CENTER FOR NEURAL ENGINEERING
AT
TENNESSEE STATE UNIVERSITY

ANNUAL PROGRESS REPORT

Period: MAY 15, 1994 to MAY 14, 1995

Submitted to

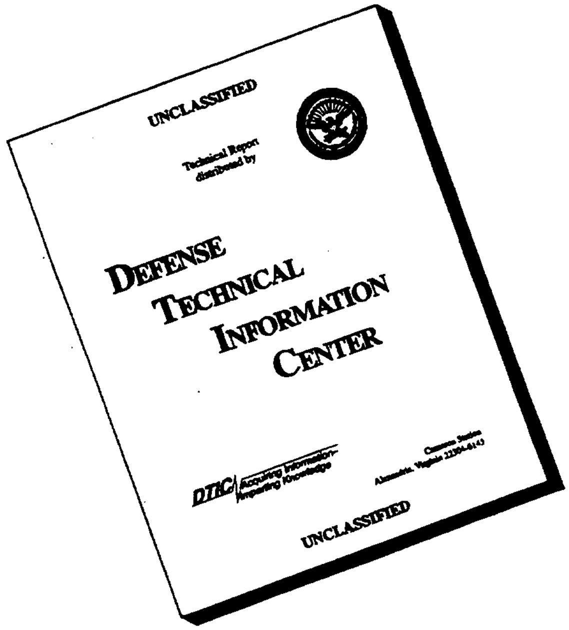
Dr. Joel Davis
Program Manager, Computational Neuroscience
Cognitive and Neuroscience Division
Office of Naval Research
(Grant # N00014-92-J-1372)

By

Mohan J. Malkani, Ph. D., Director,
Center for Neural Engineering
College of Engineering and Technology
Tennessee State University
Nashville, TN 37209-1651
malkani@harpo.tnstate.edu
(615) 963-5400

July 1995

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	JULY 1995	MAY 1994 - MAY 1995

4. TITLE AND SUBTITLE OF REPORT
Center for Neural Engineering Annual Progress Report

5. FUNDING NUMBERS
N00014-92-1372

6. AUTHOR(S)
Drs. M. Malkani, M. Bodruzzaman, J. Kuschewski,
G. Yuen and S. Zein-Sabatto

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Tennessee State University
3500 John Merritt Blvd.
Nashville, TN 37209-1561

8. PERFORMING ORGANIZATION REPORT NUMBER:

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER:

11. SUPPLEMENTARY NOTES:

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words) This third annual report provides an overview of the research activities carried on in the Center for Neural Engineering (CNE) comprising consortium partners: Tennessee State University (TSU), Meharry Medical Colleg (MMC), Accurate Automation Corporation (AAC) and Oak Ridge National Laboratory (ORNL). A team of eight (8) researchers along with eight (8) undergraduates, six (6) graduates and one (1) Ph.D student from MMC conducted research at the Center. The Center conducted research in Neural computation using the experimental data on evoked potential from rat's auditory cortex, and on the performance of a neural network designed to perform a memory-based spatial navigation task, using data from hippocampal region. CNE also applied various neural network architectures and algorithms in the areas of auditory response, speech coding, neuromuscular signal decomposition and prothesis control, sensory motor control systems and intelligent aircraft control system. As a spin-off CNE was awarded a technology transfer research project from NASA in robotics under the STTR initiative.

14. SUBJECT TERMS
Neural networks, AuditoryCortex, Hippocampus,
Spatial Navigation, Speech Coding and Sensory Motor Control

15. NUMBER OF PAGES:

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT:	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	unlimited

MESSAGE FROM THE DEAN

The Center for Neural Engineering was established in the College of Engineering and Technology in May, 1992, with a grant in excess of $1.3 million from the Office of Naval Research to conduct research in neural networks.

During the past three years, the Center has witnessed the growth of partnerships with other industries (small and large) and universities (HBCU/MI and others).

As a spinoff, the Center has successfully competed for additional research projects from NASA (especially STTR) DOE, National Security Agency, McDonnell Douglas and Lockheed Martin (ORNL Manufacturing Center).

The College of Engineering and Technology wishes to express its pride in the achievement of Center researchers, and the quality of their research, as evidenced by the increase in the number of publications and presentations at the regional, national, and international conferences. We are also proud of the caliber of our students, both undergraduate and graduate, involved in this exciting critical technology of biologically inspired neural networks.

Decatur B. Rogers, P.E., Ph.D.
Dean, College of Engineering and Technology

Contents

List of Figures

List of Tables

Summary

This third annual report provides an overview of the research activities carried on in the Center for Neural Engineering (CNE) comprising consortium partners: Tennessee State University (TSU), Meharry Medical College (MMC), Accurate Automation Corporation (AAC) and Oak Ridge National Laboratory (ORNL).

The format for the report is provided by the sponsor, Office of Naval Research for HBCU Science and Engineering Education Programs. A team of eight (8) researchers along with eight (8) undergraduates, six (6) graduates and one (1) Ph.D. student from MMC conducted research at the Center. At the suggestion of BOD, CNE management secured the services of Dr. Charles Glover from ORNL as technical monitor cum research advisor to the Center. ORNL was compensated major part of the year for 45% of Dr. Glover's time to the Center. Dr. Glover served as a liaison and pulled the resources of AAC and ORNL available to TSU and MMC researchers. This has led to three graduate students working on their masters thesis at AAC, MMC and ORNL. TSU also assisted one Ph.D student at MMC by performing signal analysis of his data on evoked potential from rat's auditory cortex. It is expected that such continued interaction between the consortium partners will assist the center in utilizing the vast resources available among consortium partners.

The Center wishes to thank the Board of Directors; Dr. Bill Appleton, Mr. Donald Campbell, Dr. Joel Davis, Dr. Harold Szu and Dr. James Townsel for their guidance and valuable suggestions for the growth of the Center. The Center used ONR grant as a leverage to attract an additional four grants from DOE, NASA, DoD and NSA to apply neural network technologies to their problems. The BOD approved distinguished lecture series at the Center continues to bring top notch researchers in neuroscience/neuroengineering to interact with Center researchers. The CNE was also awarded a technology transfer research project from NASA under the STTR initiative. Dr. Zein-Sabatto's STTR project was one of only seven proposals out of 72 that was funded by NASA. In addition, the CNE along with Vanderbilt University's Center for Intelligent Systems, has created a monthly lecture series to promote scholarly activities between the two neighboring universities.

This report summarizes the faculty activities, curriculum changes/enhancement, student activities and facilities supported by this grant. The program objectives for the next year and the interaction among consortium partners are also mentioned.

1 Goals and Objectives

The main objectives of the Center are:

1. To advance the understanding of biologically motivated neural network systems through inter-disciplinary basic research.
2. To develop the highest quality undergraduate and graduate curricula in neural computing and engineering that will serve as a role model for other institutions.
3. To provide pre-graduate and post-graduate training for students in a nationally and internationally recognized basic and applied research and development environment focusing on critical present and future technologies.
4. To broaden educational and career development opportunities for minorities and for women.

The Center addressed the above objectives through the following specific tasks:

1. Develop an intelligent aircraft control system testbed for real-time hardware/software miniature helicopter control. The testbed is created for center researchers to test advanced (possibly neural network based) control algorithms, and for student senior projects, masters thesis, and research projects. In addition, expertise gained in the development process will be applied to other ongoing and proposed Center testbeds.
2. Develop a recurrent neural network based discrete dynamic system parameter identifier and state estimator. Training of this neural network is done by a real-time temporal supervised learning algorithm.
3. Apply fuzzy, and possibly modular, neural networks to the design of a compact, real-time representation of aerodynamic data that is capable of executing on an on-board aircraft flight computer. Specifically, the neural network is to represent stability and control derivative terms that are used by the flight control algorithms.
4. Apply various neural network architectures and algorithms in the areas of auditory response, speech coding, neuromuscular signal decomposition and prosthesis control, and sensory motor control systems.
5. Design and optimize software environment for PC-based Neural Network Processor (NNP) which includes programming both for the PC and NNP and design a neural network that can be implemented on the NNP which maps changing plant parameters into controller coefficients.
6. Develop a neural network-based system which will mimic the auditory response from a rat's auditory cortex exited by successive pure tones. The data is provided by Meharry Medical College.

7. Develop a new robot actuator (servomechanism) based on biological principles and also develop a neural network-based sensory motor control suitable for robot control applications. These involve developing neuron models, neural network architectures, and training algorithms.

8. Conduct research through experiments in the Meharry Medical College to:

   - Study morphological and neurochemical organization of afferents to mammalian auditory cortex. The general protocol includes retrograde tracing to determine the projection pattern for the neurons being studied; histochemistry allows us to document the neurochemical identity of the projection systems.
   - Determine function contributions of afferent projection systems to auditory cortex. Subsequently, sound elicited responses will be studied and compared to responses during the pharmacological manipulation of projection system discharge and/or receptor blockade. It should be stressed that these perturbations are generally reversible. The working hypothesis for these experiments suggests that the overall behavior of a cortical neuron can be uniquely described by the dynamic properties of its afferent projection. Therefore, the long range goal of these studies is to describe the component function contribution of cortical afferents, particularly global subcortical-cortex systems. Information from these studies should be readily adaptable to design engineering and sensory information processing systems.

9. Develop a graduate thesis through the assistance from consortium partner Accurate Automation Corporation in the area of neural network design for dynamic controller of helicopter.

10. Provide research experience for undergraduate and graduate students in the the area of biological auditory and sensory motor system, neural networks and chaos and help undergraduate students complete their senior projects.

11. Provide professional development activities for research faculty through the attendance to national meetings, short courses and seminars.

12. Present papers at regional, national, and international conferences.

13. Publish papers in Conference Proceedings and Scientific Journals.

2 Faculty Mentoring Activities At The Center

Dr. Ann Blackshear (biology), Dr. Mohammad Bodruzzaman (elect. engr.), Dr. Saleh Zein-Sabatto (elect. engr.), Dr. Hubert Rucker (physiology, MMC), Dr. Chuck Glover (ORNL) and Dr. Kevin Priddy (AAC) guided eight (8) undergraduate students (7-elect. and 1-mech. engr.), six (6) graduate students (elect. engr.), and one (1) Ph. D. student (physiology) on various projects as discussed below.

Dr. Geoffrey Yuen supervised three graduate and one undergraduate students. They are Carolyn Keaton, Jarvis Spruill, Srinivasa Ramamarthy and Erica Hopkins. All the graduate students are expected to obtain their Masters degrees by the end of 1995. Dr. Yuen also visited Northeastern Ohio Universities College of Medicine as well as Meharry Medical College to initiate and develop collaborative research projects with the Center. This interaction provides further neurobiological ideas to Jarvis Spruill's Master thesis project on spatial memory-based navigation networks.

Dr. Bodruzzaman supervised four undergraduate and one graduate students. They are Edna Jones, Kevin McFarren, Christopher Mosby, Stephanie Smith and Timothy Robinson respectively. Edna Jones and Stephanie Smith completed their senior projects on time and graduated in December 1994 and May 1995 respectively. Kevin McFarren and Christopher Mosby left for the industrial summer job and will join again from the fall 1995 to complete their senior projects. Timothy Robinson worked on neural network application to design neuorocontroller for helicopter. He also presented and published one paper in the SPIE'95 conference and also he will be presenting a paper in the WCNN'95 Conference in Washington DC in July 17-21, 1995. He has finished his Masters thesis and is expected to graduate in August 1995. His thesis was jointly suppervised by Dr. Bodruzzaman (TSU) and Dr. Priddy (Accurate Automation Corp.).

Dr. Hubert Rucker and Dr. Sanika Chirwa's laboratories were selected as a consortium (subcontractor) laboratories. These laboratories have ongoing research programs in which biological data was collected with potential utility in the development of new neural networks.

Dr. Saleh Zein-Sabatto conducted mentoring activities throug the regular research meetings and appointments. All students made research presentations and they were provided with constructive criticism at the time. Other mentoring activities include monthly written progress reports and semester progress reports from each student. During the Fall of '94 and Spring of '95 semesters three undergraduates and two graduate students were supervised by Dr. Zein-Sabatto under research supported by CNE/ONR. The student's names are: Larry Word, Marion Bullard and Tretessa Johnson (undergraduates), Vivian Dorsey, Jarvis Spruill (graduate). In the Spring of '95 Tretessa Johnson completed her senior project and graduated in May 1995. Tretessa conducted her research in consortium with MMC.

Dr. Kuschewski co-advised (with Dr. Zein-Sabatto) two graduate students: Vivian Dorsey and Othman Al-Smadi.

Dr. Glover and Dr. Malkani advised Bridgitte Bundrage. Bridgitte graduated in May 1995 with a Master of Engineering degree.

Of the fifteen students, fourteen (8 female and 6 male) are U.S. born African-American. Table 1 presents the academic and research information for these students.

Table 1: Student academic and research information.

Name	Major	Class	Research Project Title	Advisor(s)
Bridgitte Bundrage	EE	Graduate	Neural network approach to tracking multiple objects	Dr. Glover Dr. Malkani
Marion Bullard	ME	Senior	Neurocontroller for working robot	Dr. Zein-Sabatto
Vivian Dorsey	EE	Graduate	Design of artificial limb using spherical joints	Dr. Zein-Sabatto
Erika Hopkins	EE	Junior	Phone recognition using a neural network preprocessor	Dr. Yuen
Edna Jones	EE	Senior	Chaotic hardware and neural network modeling	Dr. Bodruzzaman
Carolyn Keaton	EE	Graduate	Training oscillatory neurons with a frequency-dependent learning rule	Dr. Yuen
Tretessa Johnson	EE	Senior	Neuron model for plausible neural network design	Dr. Zein-Sabatto
Kevin McFerren	EE	Junior	Neural network based speech processing	Dr. Bodruzzaman
Christopher Mosby	EE	Junior	Neural network based speech processing	Dr. Bodruzzaman
Timothy Robinson	EE	Graduate	Stable adaptive control utilizing artificial neural networks	Dr. Bodruzzaman Dr. Priddy
Stephanie Smith	EE	Senior	Neural network based prosthesis control	Dr. Bodruzzaman
Larry Word	EE	Senior	Design of neurocontroller for inverted pendulum	Dr. Zein-Sabatto
Srinivasa Ramamarthy	EE	Graduate	Phone recognition using a neural network preprocessor	Dr. Yuen
Eric Floyd	Physiology MMC	Ph.D	Effect of chronic ethanol ingestion in the auditory cortex of rats	Dr. Rucker
Jarvis Spruill	EE	Graduate	Memory based spatial navagation and landmark learning	Dr. Yuen Dr. Chirwa

3 Student Projects

1. **Memory Based Spatial Navigation and Landmark Learning** (Jarvis Spruill, graduate student, Graduation Date: December 1995, Advisor: Dr. Yuen).

   The goal of this project is to study the effect of a new synaptic learning rule (i.e. frequency-dependent synaptic enhancement and depression) on the performance of a neural network designed to perform a memory-based spatial navigation task. Since the latter is based on a neural network patterned after hippocampal and associated circuitry, the use of a more biologically realistic learning rule (frequency-dependent synaptic modification) will enhance the performance of such a neural network. The current network consists of 6 layer of neurons and uses a combination of Hebbian and reinforcement-like learning rules and has impressive performance with respect to short training time and qualitative resemblance to searches performed by real animals (e.g. rats).

2. **Training Oscillatory Neurons With a Frequency-Dependent Learning Rule** (Carolyn Keaton, graduate student, Graduation Date: December 1995, Advisor: Dr. Yuen).

   Studies of single biological neurons and long-term potentiation in recent years suggest that a good representation of brain-like computation would include two critical ingredients: [1] Nonlinear oscillatory neurons and [2] Frequency-dependent synaptic learning rules. However, it is unclear how these factors will affect algorithms and training. The goal of this project is to investigate ways to train a small network of this type of system automatically. Nonlinear oscillating neurons based on Dr. Yuen's previous work and Hodgkin-Huxley modelling have been created in the GENESIS simulation environment. The next stage will investigate the implementation of the frequency dependent synaptic learning rule and the resulting issues of how to construct an efficient algorithm for training.

3. **Phone Recognition Using a Neural Network Preprocessor Based On Early Hearing** (Srinivasa Ramamarthy, graduate student, Graduation Date: May 1996, Advisor: Dr. Yuen) and (Erica Hopkins, undergraduate, Graduation Date: May 1997, Advisor: Dr. Yuen).

   A fundamental problem that has been overlooked in most speech-recognition systems to date is the recognition of individual and small group of phones (i.e. consonants or vowels). Due to this deficit, many current systems are unable to handle speaker independence, deteroiate quickly in the presence of noise and become unrobust on the word and sentence levels. The goal of this project is to tackle this low level phone recognition problem by abstracting from the early auditory system[1] a biologically inspired preprocessing network for phones and small groups (3) of phones. Psychophysical studies have shown that this problem is solved to an extremely high order of accuracy (99-100%) and reinforce the idea that a biological preprocessor beyond the cochlea can

[1]A concept analogous to early vision; the neurons that deal with the early stages of auditory processing, this includes the hair cells and all the hearing-related neurons leading up to the auditory cortex.

open the way to robust speech recognition in the near future. Prototypical neurons have also been implemented in GENESIS, although more software tools and phone data are currently being sought for this project.

4. **Neuron Model For Plausible Neural Network Design** (Tretessa Johnson, undergraduate, Graduation Date: May 1995, Advisor: Dr. Zein-Sabatto).

   In this senior project a neuron model for plausible neural networks has been designed for practical applications in engineering. A TTL Integrated Circuit (IC) and passive components were used to construct the model. Matlab based software is written to create a software model of the modeled neuron. The software and the hardware models produced the type of output a biological neuron produces when responding to various action potential with different frequencies. The developed neuron model was able to response to only one frequency of the input stimuli and it was verified by the hardware model.

5. **Design of Artificial Limb Using Spherical Joints** (Vivian Dorsey, graduate student, Graduation Date: August 1996, Advisor: Dr. Zein-Sabatto).

   This project involves the design of a 4-DOF robot arm similar to a human arm. A neural network based controller will be designed and trained to control the arm. The trained neurocontroller generates the proper control signal for the spherical joints in order to produce a motion similar to a human movement. This project simulates how a biological system produces motion such as a biological shoulder or arm.

6. **Stable Adaptive Control Utilizing Artificial Neural Networks** (Timothy Robinson, graduate student, Graduation Date: August 1995, Advisor: Dr. Bodruzzaman (TSU) and Dr. Kevin Priddy (AAC)).

   Helicopters are highly nonlinear systems that have dynamics that change significanlty with respect to environmental conditions. The system parameters also vary heavily with respect to flight velocity. These nonlinearities limit the use of traditional fixed linear controllers, since they can make the aircraft unstable. The purose of this research is to make contributions to the development of an "intelligent" control system that can be applied to complex problems such as this. Using slowly changing, simplified nonlinear models as examples, a controller is used that has the ability to learn from these example plants and generalize this knowledge for previously unseen plants. This knowledge can also be used to adjust the controller, maintaining stability. The adaptability comes from a feedforward neural network trained with backapropagation that adjusts the coefficients of the controller to meet the desired flight criteria. A graphical simulation program demonstrates this concept for a step input and the given control objectives. A block diagram of the proposed solution is given in Figure 1.

7. **Chaotic Hardware and Neural Network Modeling** (Edna Jones, Undergraduate, Graduation Date: December 1994, Advisor: Dr. Bodruzzaman).

   The purpose of this project is to design hardware that will produce a chaotic signal and train a neural network to capture the dynamics of that chaotic system. Firstly, the chaos signal was simulated by using two mathematical models, Logistics and Lorentz

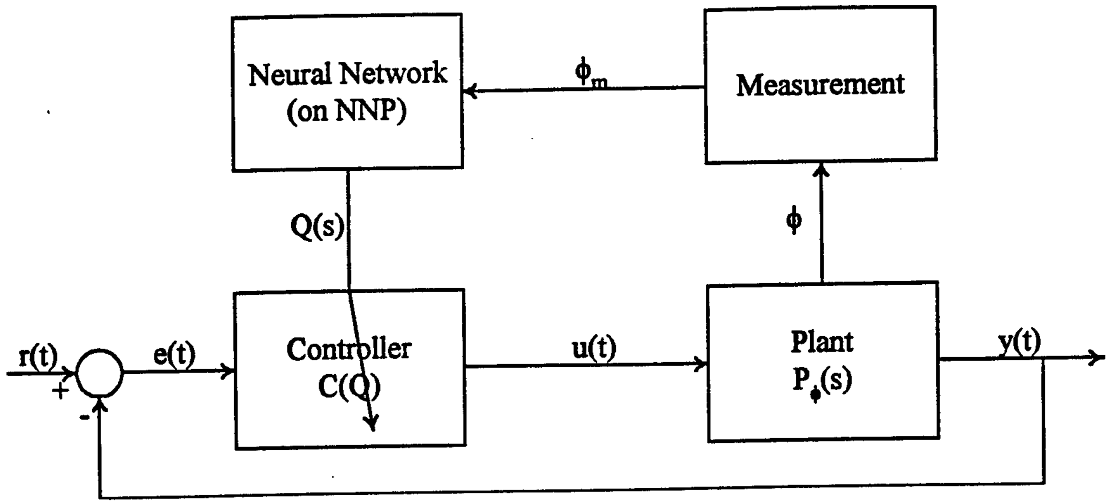


Figure 1: Proposed solution for a stable, adaptive control system.

systems. After the completion of training within 5% error, the network predicted data was tested using correlation dimension measurement. The next phase was to design an electronic circuit to produce a chaos signal. The various states of the system were obtained using integration of the velocity and position states of the signal from the circuit. These data sets were collected on a computer using an analog-to-digital converter. These data were then tested in a phase space diagram by looking at it's chaotic attractor on the oscilloscope (using analog signal) and on the computer (using digitized data). The digitized circuit data were then used to train a feedforward neural network to model and capture the dynamics. The result of the modeling was tested by phase plotting of the neural network synthetic data. The data was highly nonlinear and the training error for the velocity and position states of the signal were 23% and 30% respectively. However, it was proved that, on the whole neural network is an efficient tool for modeling of chaos data. A block diagram of the system is given in Figure 2.

8. **Neural Network Based Prosthesis Control** (Stephanie Smith, undergraduate, Graduation Date: May 1995, Advisor: Dr. Bodruzzaman).

   The purpose of this project was to design, train, and test a neural network that will discriminate a set of four lower arm functions using surface Electromyographic (EMG) signals collected from the human biceps. The functions included forearm flexion, extension, right rotation, and left rotation. In addition, a graphics program was also designed to simulate the response of the prosthesis to incoming stimuli. First, the EMG signals were collected using Biopac software and equipment. Next, a Fourier transform was performed on each signal. Having completed the transform, the slope, intercept, mean frequency, and the energy of each signal were calculated. These four characteristics were then used to achieve signature discrimination and to train the network. A total of 120 input-output pairs (30 pairs each for elbow flexion, elbow extension, right rotation

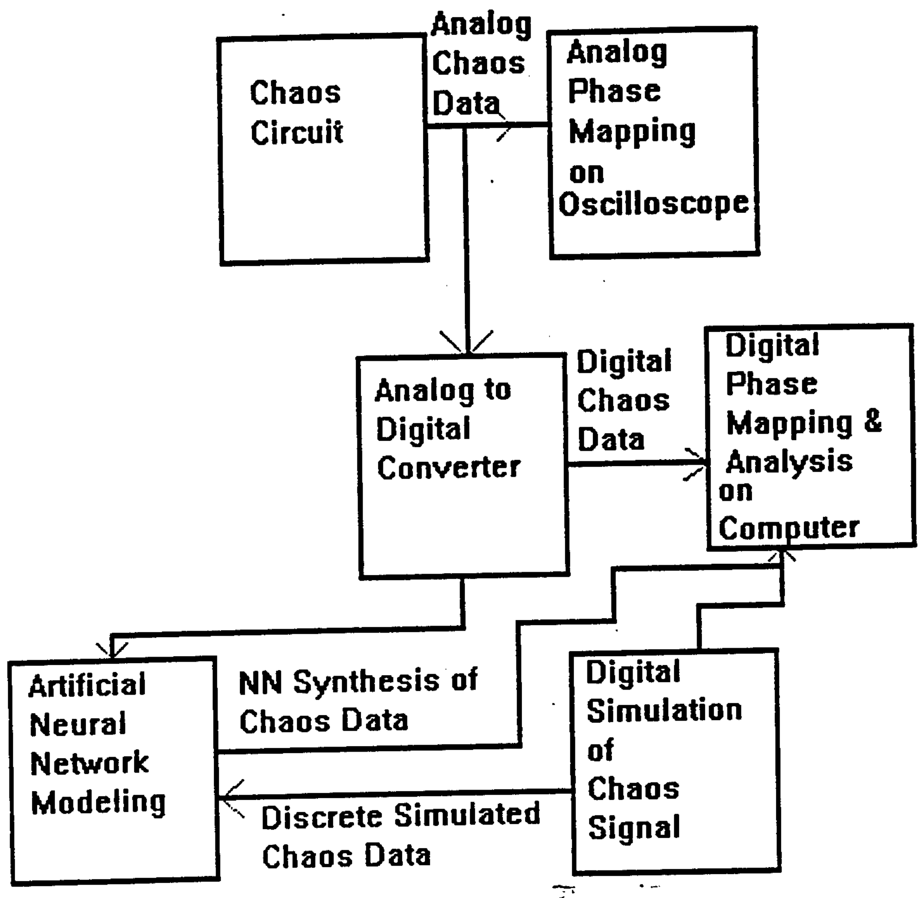


Figure 2: Block diagram of system.

of the forearm, and left rotation of the forearm) were created of which 80 pairs were used for network training. After completion of training within five percent error, the remaining 40 data pairs were used to test the network. Upon classification of the input data, the network calls upon a subroutine of the graphics program corresponding to the particular input signal to simulate the resulting operation of the prosthetic device. A block diagram of the system is given in Figure 3.

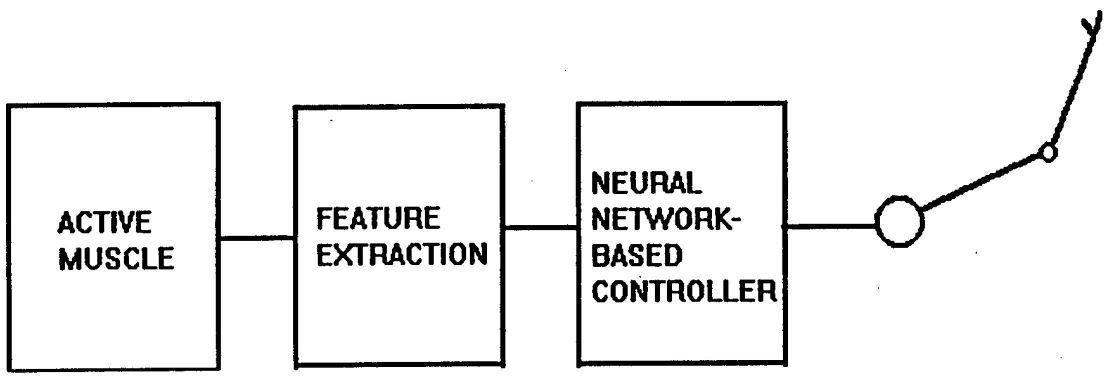


Figure 3: Block diagram of system.

9. **Neural Network Approach to Tracking Multiple Objects** (Bridgitte Bundrage, graduate student, Graduation Date: May 1995, Advisor: Dr. Charles Glover (ORNL) and Dr. Mohan Malkani (TSU)).

High energy physics (HEP) experiments involve accelerating two beams of charged particles in opposite directions around a ring of superconducting magnets and colliding them at interaction points in a detection chamber. These primary particle collisions occur every 4 nsec, from each interaction emerges thousands of secondary particles. However, only 10-100, out of 10^8 events, may be collisions where the underlying physics is new; these occurances are reffered to as interesting events. Physicists are interested in studying the highest energy particles which produce straight or slightly curved tracks. A decision is required every 10-50 μsecs on whether to keep the data from the collision for further analysis.

A fast tracking method is thus essential for the high energy physics (HEP) problem. The current techniques used to reconstruct the tracks of charged particles are performed off-line; the algorithms can be slow and are inefficient if implemented in VLSI hardware. Neural networks are attractive because of their completely parallel algorithms and for their ease into VLSI implementation. This project summarizes a neural network approach to reconstructing the tracks of charged particles when the data is presented in a single readout. The computational results verify that the algorithm successfully traces the tracks of charged particles, even under noisy conditions. In addition, this

algorithm is fully capable of finding temporal tracks of objectives as well. Consequently, it should be a good candidate for VLSI implementation.

10. **Neural Network Based Speech Processing** (Kevin McFerren, undergraduate, Graduation Date: December 1996, Advisor: Dr. Bodruzzaman).

    This project involves the speech data collection from student samples, record the data in ascii format so that they could be loaded into the Matlab environment, and use signal processing tools to extract features to be used for neural network training and testing for speaker recognition.

11. **Neural Network Based Speech Processing** (Christopher Mosby, undergraduate, Graduation Date: December 1996, Advisor: Dr. Bodruzzaman).

    This project also involves the speech data collection, writing matlab code for signal processing-based feature extraction and neural network-based training and testing for speaker recognition. This project also involes feature extraction from speech data using wavelet transformations.

12. **Design of Neurocontroller for Inverted Pendulum** (Larry Word, undergraduate, graduation date: May 1996, Advisor: Dr. Zein-Sabatto).

    This project involves the design and implementation of a neural network controller to control the inverted pendulum available at the Department of Electrical and Computer Engineering's Controls Lab.

13. **Neurocontroller for Working Robot** (Marion Bullard, undergraduate, graduation date: May 1997, Advisor: Dr. Zein-Sabatto).

    The goal of this project is to design a controller based on a neural network to control the motion of a working robot designed by a group of students from the Mechanical Engineering Department.

4 Faculty Research Highlights

4.1 Research Activities of Dr. Geoffrey L. Yuen

Dr. Yuen conducted research in following areas:

1. Completed derivation of the equations of motion (dynamics) for the 2-D pole balancer (i.e. 2-D inverted pendulum control) using the Lagrangian method. Completed an initial study using the classical Barto-Sutton reinforcement learning network controller. Demonstrated that the classical architecture cannot handle the 2-D problem with eight state variables (and 11,000 states to learn). Further progress requires a neural network controller that can perform efficient learning in high dimensional state space and a very efficient partitioning strategy.

2. Developed and specified collaborative computational projects related to long-term potentiation with Meharry Medical College and Northeastern Ohio Universities College of Medicine (Dr. S. Chirwa and Professor Timothy Teyler respectively): [1] PKC bidirectional synaptic control; [2] Memory-based spatial navigation.

3. Initiated and completed the first phase of a modelling study using calcium dependent activation and phosphorylation control of protein kinase C as a substrate for bidirectional synaptic weight control. Results from this particular study demonstrates for the first time how high but varying levels of calcium concentration (10-100 micromolar) can mediate synaptic depression or potentiation. Established connection with Dr. David Lester at FDA/NIH, an authority on protein kinase C biophysics who will provide subsequent biochemical and biophysical data and critique of the modelling work.

4. Initiated for the Center for Neural Engineering to perform realistic, biological neuronal and network simulations: [1] Installation of GENESIS and NEURON on Sun workstations, 486 and Pentiums personal computers; [2] Training of students in the biophysics of neural computations (3 graduate and 1 undergraduate students) and [3] Develop focused Masters thesis topics for graduate students for which more biologically realistic neuron models and learning rules are used.

4.1.1 Two-Dimensional Inverted Pendulum Control Problem

As a foundation for controlling a human-like spherical joint mechanism developed by Dr. Saleh Zein-Sabatto, the dynamic equations for discribing such a two-dimensional mechanism has been implemented as an inverted pendulum control problem to be solved by an appropriate neural network controller. The dynamics of such a two-dimensional cart-pole system has been derived using Lagrangian mechanics (work done in collaboration with Dr. John Kuschewski). The plant has 8 state variables (cf. 4 in the one-dimensional case) and the resulting equations have been implemented in Matlab and C for subsequent control investigation and testing of various neural network paradigms. A schematic diagram of the pendulum is given in Figure 4.

In terms of x, y, ϕ, and θ, the location $\mathbf{p}$ of the tip of the pole in the xyz space is

$$\mathbf{p} = \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} = \begin{bmatrix} x + l\sin\phi\cos\theta \\ y + l\sin\phi\sin\theta \\ l\cos\phi \end{bmatrix}.$$

System Dynamic Equations We use the Lagrange equations of motion to describe the dynamics of the system. The Lagrangian of the system is $\mathcal{L} = \mathcal{K} - \mathcal{U}$, or

$$\mathcal{L} = \frac{1}{2}m(\dot{p}_x^2 + \dot{p}_y^2 + \dot{p}_z^2) + \frac{1}{2}M(\dot{x}^2 + \dot{y}^2) - mgl\cos\phi.$$

The system has four degrees of freedom; hence we have four Lagrange equations of motion for the system:

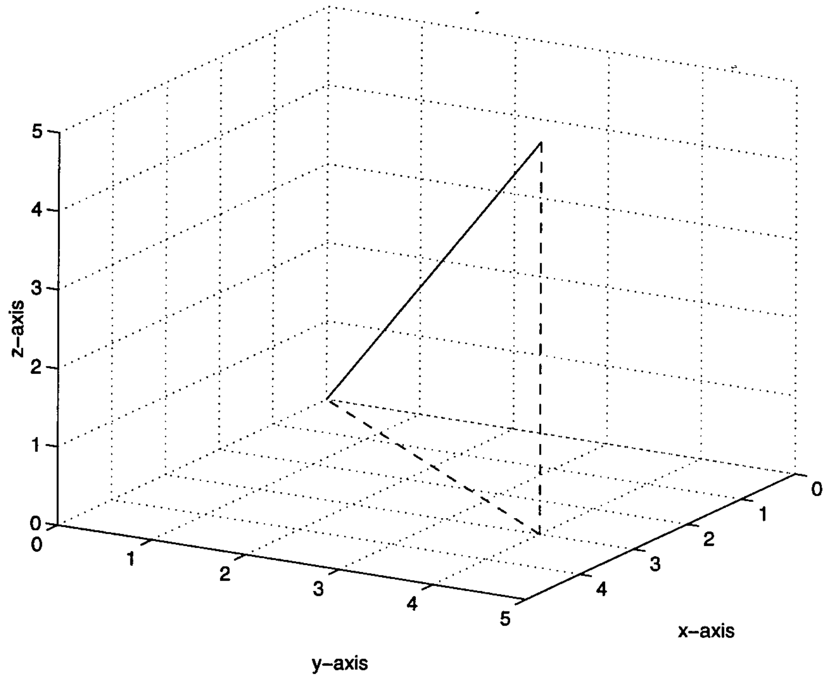


Figure 4: Schematic diagram of the 2-D inverted pendulum.

$$
\begin{aligned}
(m+M)\ddot{x} + ml[\ddot{\phi}\cos\phi\cos\theta - \ddot{\theta}\sin\theta\ sin\phi - 2\dot{\phi}\dot{\theta}\sin\theta\cos\phi - (\dot{\phi}^2+\dot{\theta}^2)\sin\phi\cos\theta] &= u_x, \\
(m+M)\ddot{y} + ml[\ddot{\phi}\cos\phi\sin\theta + \ddot{\theta}\cos\theta\ sin\phi - 2\dot{\phi}\dot{\theta}\cos\theta\cos\phi - (\dot{\phi}^2+\dot{\theta}^2)\sin\phi\sin\theta] &= u_y, \\
\ddot{x}\cos\phi\cos\theta + \ddot{y}\cos\phi\sin\theta + l(\ddot{\phi} - \dot{\theta}^2\sin\phi\cos\phi) - g\sin\phi &= 0, \\
\ddot{y}\sin\phi\cos\theta - \ddot{x}\sin\phi\sin\theta + l(\ddot{\theta}\sin^2\phi + 2\dot{\theta}\dot{\phi}\cos\phi\sin\phi) &= 0.
\end{aligned}
$$

4.1.2 A Model of Bidirectional Synaptic Control Via Protein Kinase C Regulation

Rationale Recent work has demonstrated that stimulus frequency is a primary determinant of whether synaptic depression or potentiation would be resulted for the hippocampal Schafferr-CA1 synapses. Currently, high calcium levels resulted from high frequency stimuli are thought to produce potentiation while low calcium levels from low frequency stimuli lead to depression. However, there is currently no consensus on the exact form of this dependency based on experimental studies. Bear and Dudek (1992) reported such a frequency-dependent bidirectional synaptic regulation curve but the stimulus intensity used in this study is extremely high and not reproducible in other strands of rats (Teyler, personal communication). Although Timothy Teyler and coworkers reported a requency-dependency with similar trends (i.e. depression below 10 Hz, potentiation above 10 Hz), the potentiation phase during higher frequency stimulation appears to have different and multiple slopes, in contrast to that reported by Bear and Dudek (1992). Thus there is a clear need to understand the theoretical and mechanistic basis for the observed frequency-dependency of synaptic modulation. It would be imperative to develop a model of the dynamic synaptic modulation of hippocam-

pal CA1 neurons. Previous experimental and modelling work has established calmodoulin kinase II as an important molecule for the bidirectional encoding and regulation of synaptic efficacy in CA1 (Lisman 1989). However, it is clear that other kinases, including protein kinase C is involved in such bidirectional control.

A model of bidirectional synaptic control (synaptic depression and potentiation) for hippocampal CA1 neurons based on the activation, phosphorylation and inhibition of protein kinase C (PKC) by calcium has been developed. The results show how low levels of calcium can lead to synaptic depression while higher levels can lead to synaptic potentiation. In particular, low levels of calcium allow PKC inhibitor calcineurin to produce net dephosphorylation off ON kinases, leading to a lower synaptic efficacy (see Figure 5). Conversely, when high levels of calcium is available, the autophosphorylation properties of PKC lead to net phosphorylation of OFF kinases, leading to a net potentiation (see Figure 6).

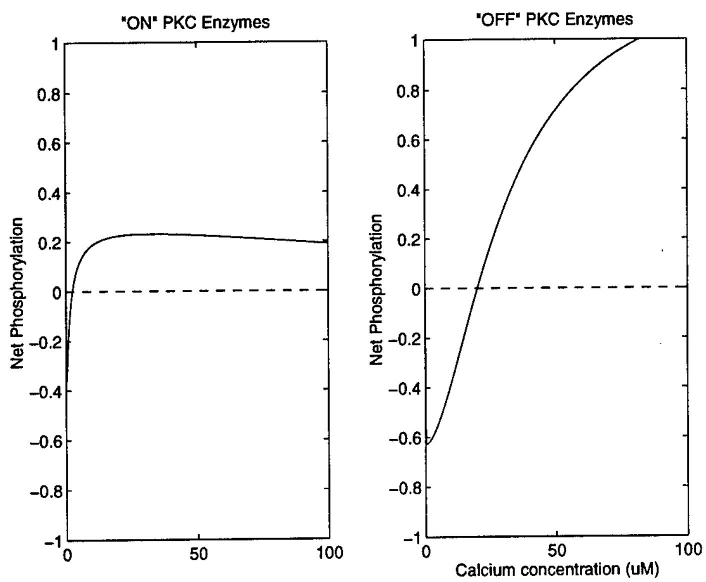


Figure 5: Bidirectional net phosphorylation of PKC without AA.

Model Assumptions This model illustrates the synergistic actions of other PKC cofactors or co-activators such as arachonic acid (AA) and diacylglecerol (DAG) in supporting a calcium-independent form of PKC (see Figure 7) and uses the following assumptions. [1] Activation data based on Shinomura et al (1991) and Huang et al (1986). [2] Gamma-PKC autophosphorylation leads automatically to membrane-insertion/calcium-independent state. [3] Calcium is the rate-limiting reagent, phosphoserine (PS) and DAG are assumed to be in abundance; dephosphorylation only proceeds via calcineurin. [4] Autophosphorylation state is "almost calcium-dependent" instead of completely calcium independent:

1. Net phosphorylation of ON-PKC : $K_{max} * (Ca^{2+}$ activation of OFF-PKC$) - P_{P2B}$
2. Net phosphorylation of OFF-PKC : $K_{max} * (Ca^{2+}$ activation of ON-PKC$) - P_{P2B}$

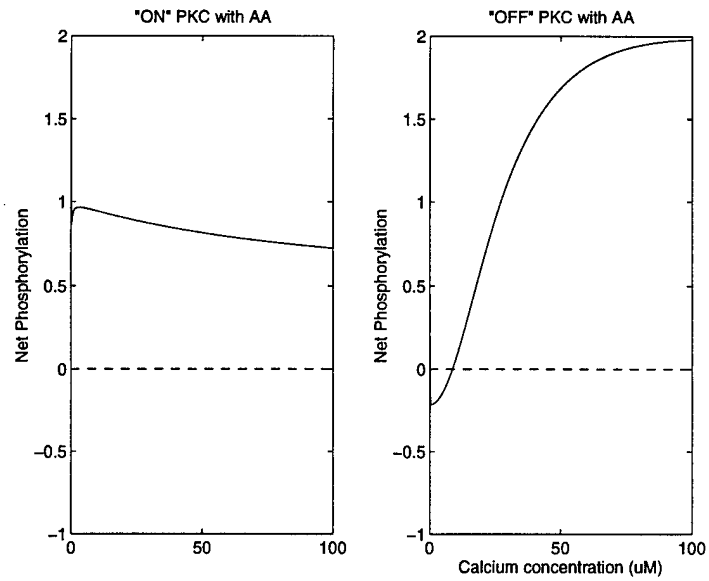


Figure 6: Bidirectional net phosphorylation of PKC with AA.

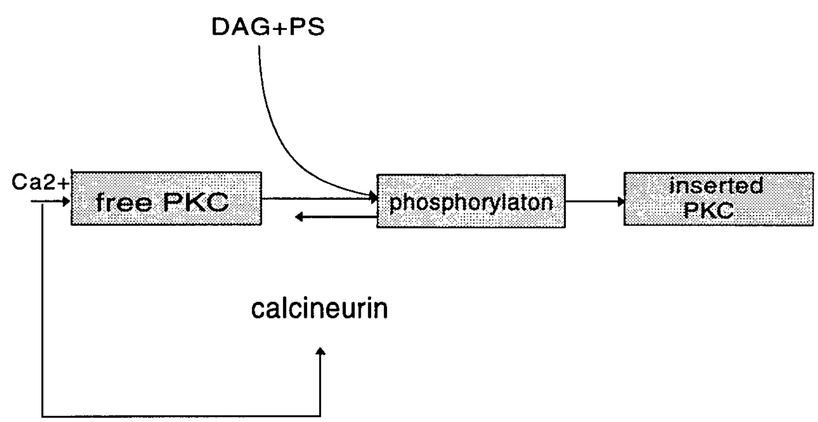


Figure 7: PKC bidirectional control model.

Significance Our results indicate for the first time that such bidirectional synaptic control is indeed possible with PKC with the expected transient levels of calcium concentration in neurons during excitation (i.e. between 10 and 100 micromolar). For comparison, analogous calculations show that calmodoulin kinase II could only operate within 1 micromolar and thus has limited useful dynamic range. Finally, this work provides the necessary ground work for the development of a time-dependent model that can account for the dynamic, bidirectional regulation of synaptic weights as a function of stimulus frequency, which will be useful for future experimental verification by Professor Timothy Teyler at Northeastern Ohio Universities College of Medicine.

4.1.3 Training Oscillatory Neural Networks With a Frequency Dependent Synaptic Modification Rule

Studies of single biological neurons and long-term potentiation in recent years suggest that a good representation of brain-like computation would include two key ingredients: [1] Nonlinear oscillatory neurons and [2] Frequency-dependent synaptic modification rules. To create useful new neural network architectures based on these insights, a few questions needs to be answered: [1] How should such a network be trained automatically (i.e. what training algorithm can be used)? [2] What are the optimal stimulus for coding and retrieval and [3] How to acheive optimal memory capacity for such a network? Nonlinear oscillating neurons similar to hippocampal cell models developed by Dr. Yuen (CA1, dentate granule cells) and a prototypical frequency-dependen synaptic modification rule are currently being implemented in the NEURON environment for efficient computation. The question of training algorithms can then be addressed by writing high-level training procedures in this environment.

4.1.4 Other Testbed Problems: Memory-based Spatial Navigation and Phone Recognition

The focus of these testbed problems have been described under the respective student project (for Jarvis Spruill and Srinivasa Ramamarthy). The new neural network architectures and training algorithms derived from the last section will be applied to thes two specific testbed problems.

References

[1] Allen, Jont B. "How do humans process and recognize speech ?", IEEE Transactions on speech and audio processing 2(4): 567-576 (1994).

[2] Barto, A. and R. Sutton, "Neuronlike Adaptive Elements that can solve difficult learning control problems", IEEE Trans Sys Man Cybern. SMC-13:834 (1983)

[3] Baudry, M. and J. Davis "Long-Term Potentiation", MIT Press, 1994.

[4] Burgess, N. et al "A model of hippocampal function", Neural Networks 7:1065-1081, (1994).

[5] Dudek, S. M., Bear, M. F. "Homosynaptic long-term depression in area CA1 of hippocampus and effects of N-methyl-D-aspartate receptor blockage", Proc Natl Acad Sci 89:4336, (1992).

[6] Huang et al "Autophosphorylation of Rat Brain Ca2+-activated and Phospholipid-dependent Protein Kinase", J Biol Chem 261:12134-12140, (1986)

[7] Lippman, Richard "Review of Neural Networks for Speech Recognition", Neural Computation 1:1-38 (1989).

[8] Lisman, J. "Feasibility of long-term storage of graded information by CaM kinase II", PNAS 85:5320-5324, 1988.

[9] Lisman, J. "A mechanism for the Hebb and the anti-Hebb processes underlying learning and memory", Proc Natl Acad Sci USA 86:9574-9578 (1989).

[10] Shinomura et al "Synergistic action of diacylglycerol and unsaturated fatty acid for protein kinase C activation: Its possible implications", Proc Natl Acad Sci USA 88:5149-5153 (1991).

4.2 Research Activities of Dr. John G. Kuschewski

Dr. Kuschewski conducted research in the following three areas:

4.2.1 Intelligent Control Helicopter Testbed

This ongoing CNE project has three main goals. First, to develop a real-time hardware and software control testbed for advanced control algorithms developed by CNE researchers. Second, to gain experience in developing such a testbed and apply it to other similar upcoming or ongoing testbed development projects. Third, to make a usable and accessable testbed for student senior project, masters thesis, or research projects. Team members include Dr. Saleh Zein-Sabatto, who is responsible for higher level project planning and design; Dr. John G. Kuschewski, who is responsible for lower level project planning and design; and Mr. Yixiong Zheng, a graduate assistant, who is responsible for hardware and software development.

The project hardware consists of a miniature helicopter, helicopter stand, dc motor, servomotors, electronic speed control, rate gyro, basic stamp microcontrollers (stamps), and power supplies. The helicopter stand provides a way to safely fly the helicopter by limiting the flight envelope. Two 12V, 30A dc power supplies connected in series power the dc motor (a gasoline engine is not possible as the helicopter testing is conducted in a laboratory). Six stamps are mounted at the front of the helicopter and are powered by a seperate 9V power supply. A 80486 based personal computer processes real-time keyboard commands and sends the resulting control signals to the communication stamp which then passes the information to the appropriate control stamp. Each of the four control stamps controls one of the servomotors which in turn adjust the helicopter control surfaces; the fifth control stamp controls the motor speed via the electronic speed control. Thus, open-loop control is

obtained. A diagram of the helicopter control system is given in Figure 18. However, note that the rate gyro provides feedback to enhance the yaw control of the helicopter. Most of the initial hardware design, building, and assembly as well as software design and development has been completed. Project documentation has also begun and is being expanded and improved. Vertical motion flight testing has been conducted in the lab; speed and elevator control of the helicopter has been successfully demonstrated. The process of adding of sensors (and possibly gyros) to the helicopter and the stand to provide position and orientation feedback information to the control system has begun; this will eventually lead to feedback control of the helicopter.

4.2.2 Discrete Dynamic System Parameter Identification and State Estimation

A recurrent neural network is used to simultaneously identify the matrices and estimate the state vector of a state-space description of a linear time-invariant, single-input single-output, discrete dynamic system, given system input and output data. A one-layer recurrent neural network containing linear neuron activation functions and delay operators corresponds to the dynamic system. Furthermore, there is a one-to-one correspondence between neural network weights and matrix elements. A real-time temporal supervised learning algorithm was used to train the neural network. The neural network based identifier/estimator is implemented as a computer simulation in Matlab.

The neural network identifier/estimator was tested on a discrete dynamic system with the following parameters: $\mathbf{A} = [\mathbf{-0.5}]$, $\mathbf{B} = [\mathbf{0.2}]$, and $\mathbf{C} = [\mathbf{1.0}]$. The input signal consists of step functions as well as portions of sine functions, and the learning rate $\eta = 0.1$. The identification/estimation structure was simulated over many trials, with different random initial weights for each trial. State estimation performance was uniformly good, i.e., the estimated state tracked the desired state very closely in most of the trials. Unfortunately, system identification performance was not uniformly good, i.e., the neural network weights converged, but not to the values of the corresponding system parameters in most of the trials. This performance is believed to be due to the fact that, for this first order system, the problem the neural network is trying to solve is underdetermined, and thus there is no unique solution for the weights to converge to. However, a good set of results is illustrated in Figure 8, where it is seen that $\mathbf{A}$ converges to $[-0.4791]$, $\mathbf{B}$ converges to $[0.1972]$, and the estimated state $\mathbf{x}(k)$ converges to the desired state $\mathbf{x}(k)$ after a period of oscillation. These positive results encourage us to modify and/or further investigate the applicability of this neural network structure and learning algorithm for parameter identification and state estimation of higher order discrete dynamic systems. Researchers on this project are Dr. Saleh Zein-Sabatto, Dr. John G. Kuschewski, and Mr. Othman Al-Smadi.

4.2.3 Intelligent Aircraft Control System

This project is a spin-off of the CNE. It is a NASA project subcontracted to CNE by McDonnell Douglas Aerospace Corporation. The goal of this project is to construct a compact, real-time representation of aerodynamic data that is capable of executing on an on-board aircraft flight computer. Specifically, stability and control derivative terms that are used by

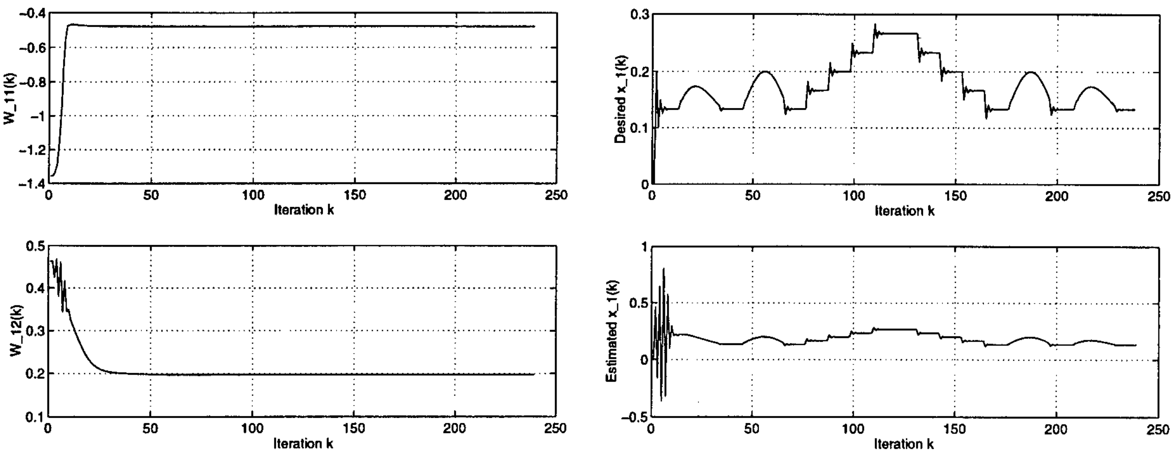


Figure 8: Time history of the estimated system parameters and the desired and estimated state.

the flight control algorithms will be modeled (represented). Expected to have some kind of neural network architecture, this representation will be constructed off-line and must be very accurate over the entire aircraft operating envelope and be capable of demonstrating correct operation for all inputs. Potential research topics include identifying and demonstrating neural network architectures that satisfy the goal criteria, incorporating new data and pruning old data, and visualization and evaluation of data and results. Two architectures will be considered: the ANFIS (Adaptive Neuro Fuzzy Inference System) and the Modular Neural Network. Team members include Dr. Mohan J. Malkani, Dr. Saleh Zein-Sabatto, and Dr. John G. Kuschewski. TSU researcher involvement will be for 9 months, beginning May 1, 1995.

The project kick-off meeting was on May 23-24 in St. Louis, MO. We met with the other researchers working on the project, presented our appoaches to solving the problem in formal meetings, and discussed specific issues of all three phases of the project in informal meetings. Specifically, the focus is on two research areas. Dr. Zein-Sabatto's research will focus on data preprocessing and analysis. Dr..Kuschewski's research will focus on developing neural network architectures to represent this preprocessed data. Although not a focus area, data and results visualization and evaluation will be an important research area.

Work since May 24th has focused on copying the large amount (over 50MB) of data files from Harpo, TSU's VAX mainframe, to Dr. Kuschewski's personal computer; understanding the format of the data files; choosing a data file to begin modeling work; using the Matlab Fuzzy Logic Toolbox to find an initial ANFIS model of the chosen data and optimizing the resulting model.

4.3 Research Activities of Dr. Hubert Rucker and Dr. Ann Blackshear

Dr. Hubert Rucker conducted research in collaboration with Dr. Anne Blackshear in the following area:

4.3.1 Chronic Ethanol Ingestion Produces Cholinergic Hypofunction in Rat Brain

The aim of this study was to determine the effects of chronic ethanol ingestion on cholinergic function by assessing changes in ChAT activity and HAChU. The level of ChAT activity in the brain is a marker of cholinergic innervation, and the HAChU system has been shown to be rate-limiting in the synthesis of acetylcholine (Kuhar). The results of this investigation demonstrate that prolonged intake of ethanol results in a significant reduction in ChAT activity and HAChU. These findings suggest that prolonged ethanol exposure may cause the death of cholinergic neurons in the basal nucleus complex.

Chronic intake of ethanol has been reported to affect a variety of neurotransmitter functions in the brain. However, the most consistent data in the literature have been obtained in studies of the action of ethanol on cholinergic transmission.

The reduction in cholinergic markers observed in the present study is more pronounced in the frontal cortex and basal nucleus complex than in the target area of the parietal cortex after six months. Arendt and coworkers have reported a gradient in neuronal loss over the rostrocadual extension of the subdivisions of the basal forebrain cholinergic projection system after chronic ethanol ingestion. This finding lends support to the assumption of a direct toxic effect of ethanol on cholinergic neurons in the basal forebrain which is then reflected secondarily by a degeneration of axon terminals in the cortex.

In the present study, ChAT activity was reduced 32% in the frontal cortex and 22% in the NbM complex after six months ethanol exposure. However, there was a 30% increase in ChAT activity in the parietal cortex. A 50% decrease in choline uptake was noted in the frontal cortex after six months exposure. This is in contrast to increased choline uptake in the NbM region (43%) and parietal cortex (178%). The decrease in ChAT activity and the apparent limited reduction in high affinity choline uptake after six months exposure may result from a decrease in neuronal density affecting a large proportion of cholinergic terminals but with a concomitant acceleration in the acetylcholine turnover rate of the surviving neurons. This may occur via a homeostatic compensation mechanism, in an attempt to maintain cholinergic tone. However, after nine months of ethanol exposure, both ChAT activity and HAChU was significantly decreased. This suggests that chronic ethanol ingestion results in a time-dependent cholinergic degeneration, which may be irreversible. In the present paradigm, this irreversibility may occur after 6 or more months of ethanol intake.

Since ethanol treatment in the present study did not result in a significant difference in body weight, it seems reasonable to attribute the observed changes in the basal forebrain cholinergic projection system to a direct toxic effect of ethanol rather than to malnutrition which usually accompanies ethanol intake.

4.4 Research Activities of Dr. Mohammad Bodruzzaman

Dr. Bodruzzaman conducted research in following areas:

4.4.1 Electromyographic (EMG) Signal Decomposition Using Kohonen Neural Net and Wavelet Network

In this work, the problem of multi-train electromyographic signal decomposition is addressed. The problem is solved by using an unsupervised Kohonen network [3, 4] using Winner-Take-All learning technique. Assuming the number of classes is not known a priori, which is the reality in a practical situation when a clinical electromyographer collects the EMG signal during a voluntary muscle contraction as shown in Figures 9 - 11, the network is allowed to grow as it detects a new pattern member. Each time a new pattern is detected, a new cluster group is formed by increasing the network output by one, and the weights connected to this new output are initialized by the pattern values. However, when a matching pattern is detected, the weights to the winning neuron are updated such that the weight vector, in the weight-space, represents the centroid of the winning cluster group. This classifier network is then applied for the decomposition of a simulated electromyographic (EMG) multi-train signal as shown in Figures 12 and 13. The proposed system is performing recognition and classification with very high performance rate even when the entire signal was corrupted with 20% noise for a normal clinical measurement environment. The decomposition of such EMG signal is very important to the clinical neurologist in diagnosing various neuro-muscular diseases such as myopathy, neuropathy etc. and to neuro-scientist to understand the biological motor control strategies in different pathologic states. The choice of unsupervised network is practical because no one knows exactly the number of motor units that will be active during a muscular contraction. Finally, the possible use of wavelet network is also proposed to replace the Kohonen network once the super mother wavelet set (a set of mother wavelets) is captured by the Kohonen neural network. That is, use Kohonen net for preprocessing, download the super mother wavelet set to the wavelet network and then use wavelet network for real-time clinical classification.

4.4.2 The Kohonen Network and Winner-Take-All Learning

The unsupervised classification of learning is based on clustering of input data. No a priori knowledge is assumed to be available regarding an input's membership in a particular class. Rather, gradually detected characteristics and history of training will be used to assist the network in defining classes and possible boundaries among them.

Clustering is understood to be the grouping of similar objects and separating of dissimilar ones. Suppose we are given a set of patterns without any information as to the number of classes that may be present in the set. The clustering problem in such a case is that of identifying the number of classes according to a certain distance criterion, and of assigning the membership of the patterns in these classes.

Unsupervised classification and clustering is an appropriate tool for the decomposition of EMG signal because the number of classes is not known apriori. When a pattern is detected

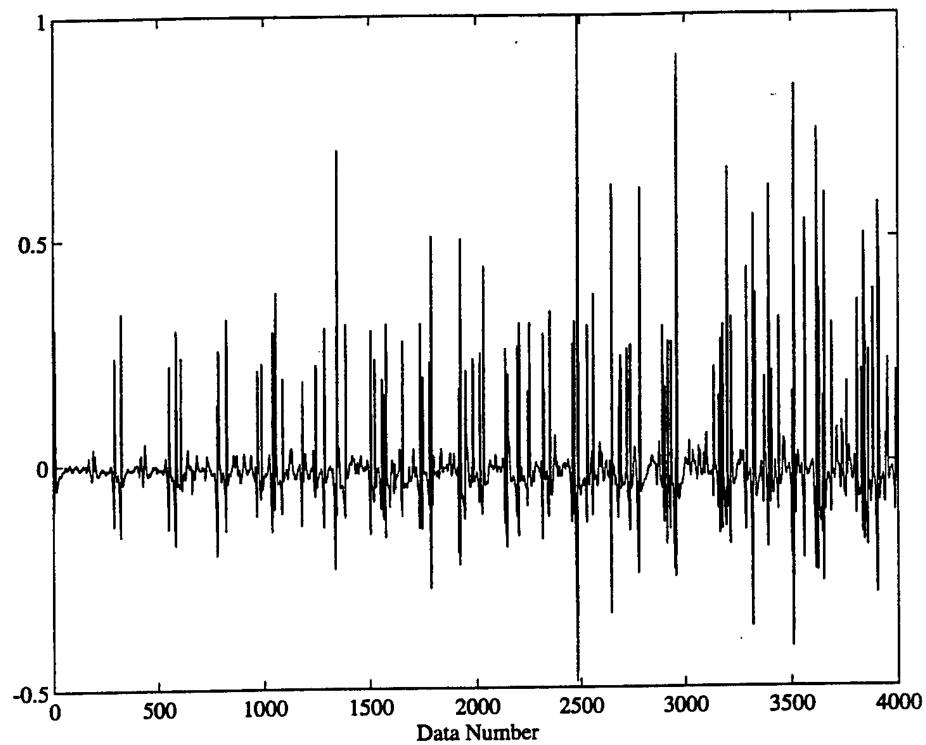


Figure 9: Real EMG signal from human biceps during contraction.

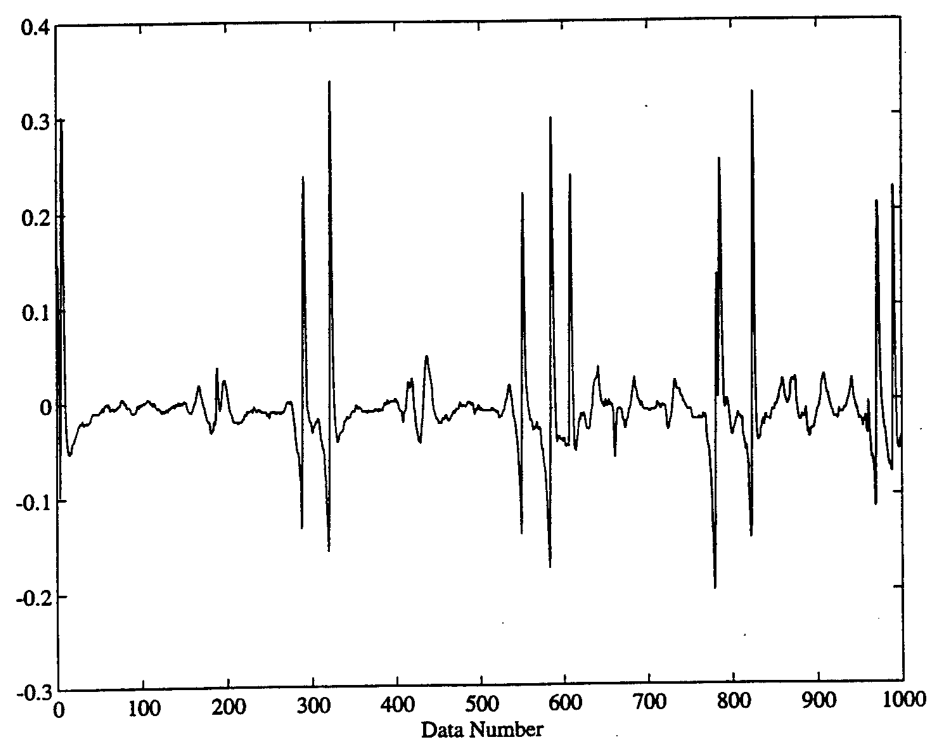


Figure 10: First 1000 (0.75 secs) real EMG data.

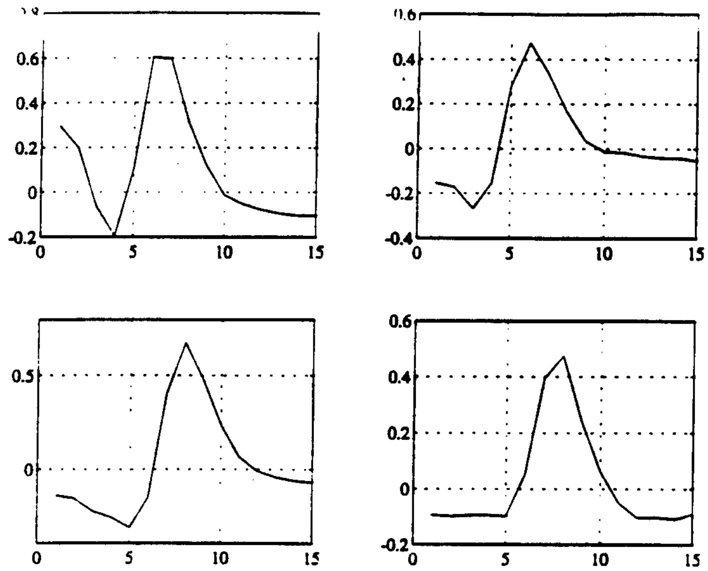


Figure 11: Sample action potentials deduced from real EMG data.

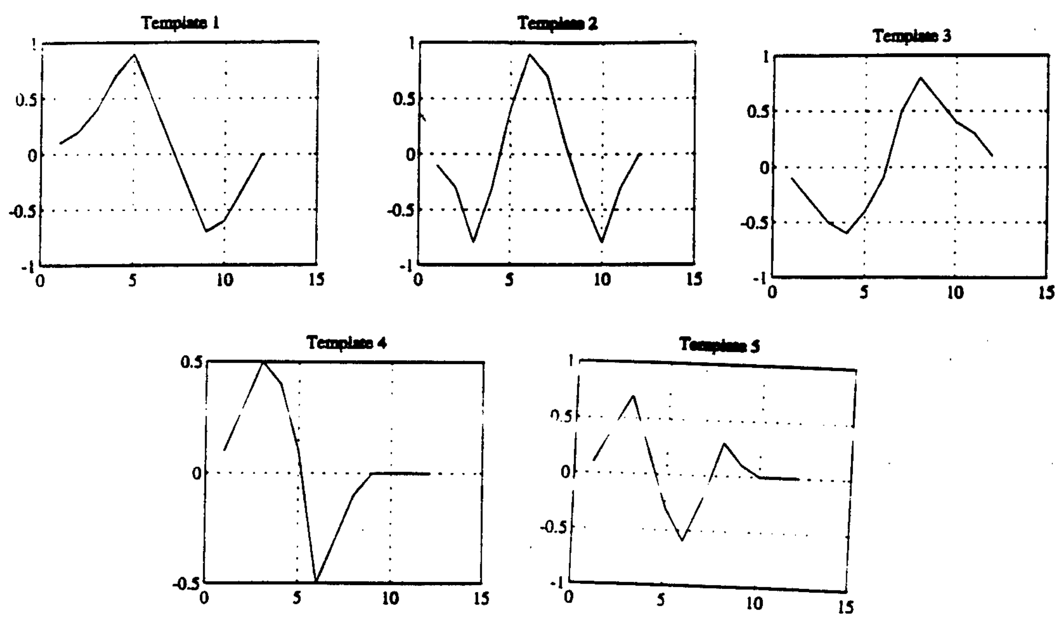


Figure 12: Simulated MUAPTs: typical templates.

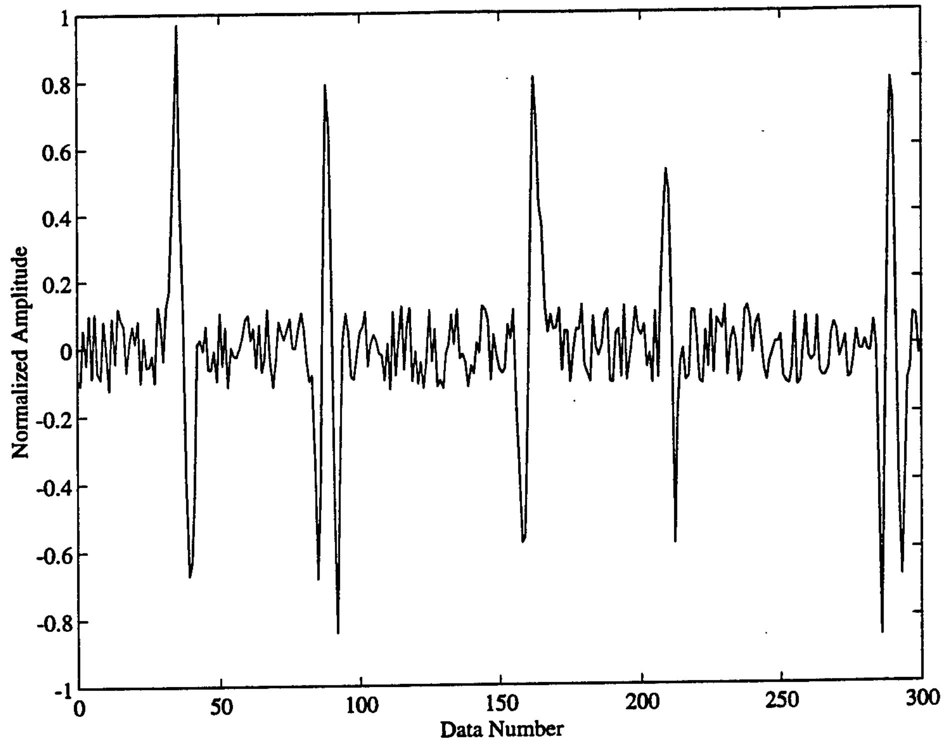


Figure 13: Simulated EMG signal (with 20% noise).

by a moving window-based detector, it is then presented to a feedforward Kohonen network where the training is performed in an unsupervised mode using a competitive Winner-Take-All learning rule [5]. During the training, when the scalar product of the input pattern vector and neuron weight vector crosses a predetermined threshold (i.e. when a matching pattern is detected), the weights of the winning neuron are updated such that the weight vector, in the weight-space, represents the centroid of the winning cluster group. Since the number of classes is not known a priori, the network is allowed to grow as it detects a new pattern member. Each time a new pattern is detected, a new custer group is formed, the network output size in increased by one, and the weights connected to this new output are initialized by the pattern values. Only the winning node with the largest output is rewarded with a weight adjustment, while the weights of the others remain unaffected. While learning continues and clusters are developed, the network weights acquire similarity to input data within clusters.

4.4.3 EMG Signal Decomposition Using Kohonen Network

A block diagram of the proposed Kohonen network-based neuro-muscular signal decomposition system is shown in Figure 14. A moving window-based spike detector is used for the detection of the presence of action potentials as the window moves along the entire EMG data. The spikes are identified whenever they crossed a predetermined threshold and then presented to the Kohonen network for classification. The decomposition system graphically plots the corrupted multi-train EMG signal and also plots the classified action potentials into decomposed channels as shown in Figure 15.

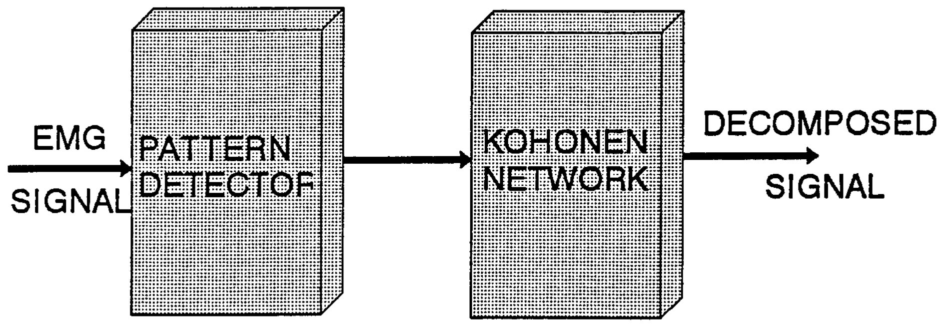


Figure 14: Block diagram of the signal decomposition system.

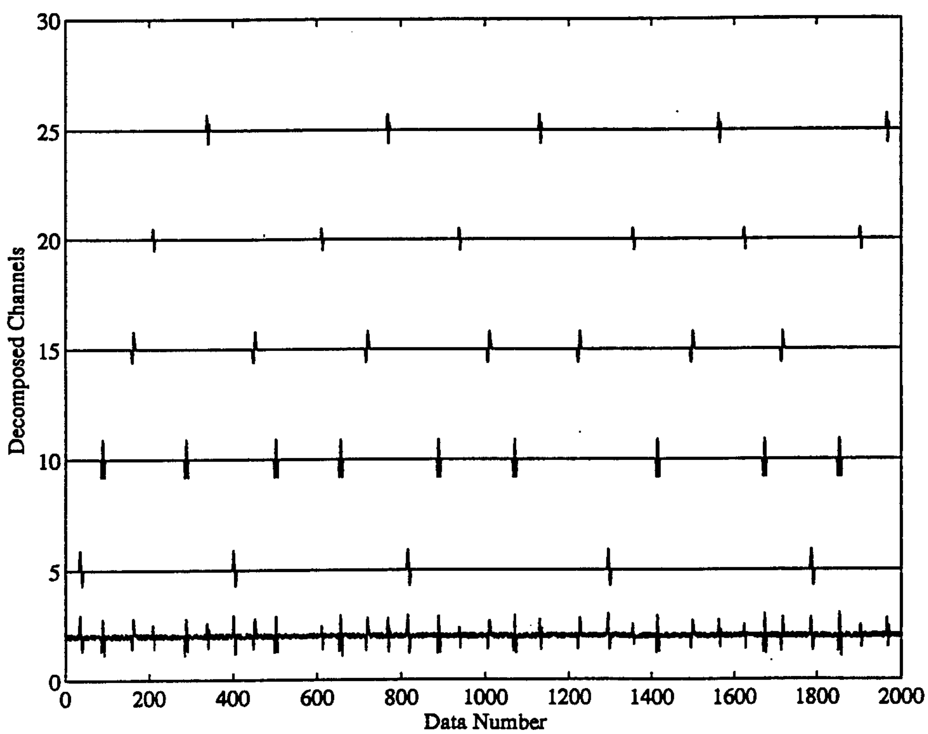


Figure 15: The corrupted EMG signal and its decomposed MUAPTs.

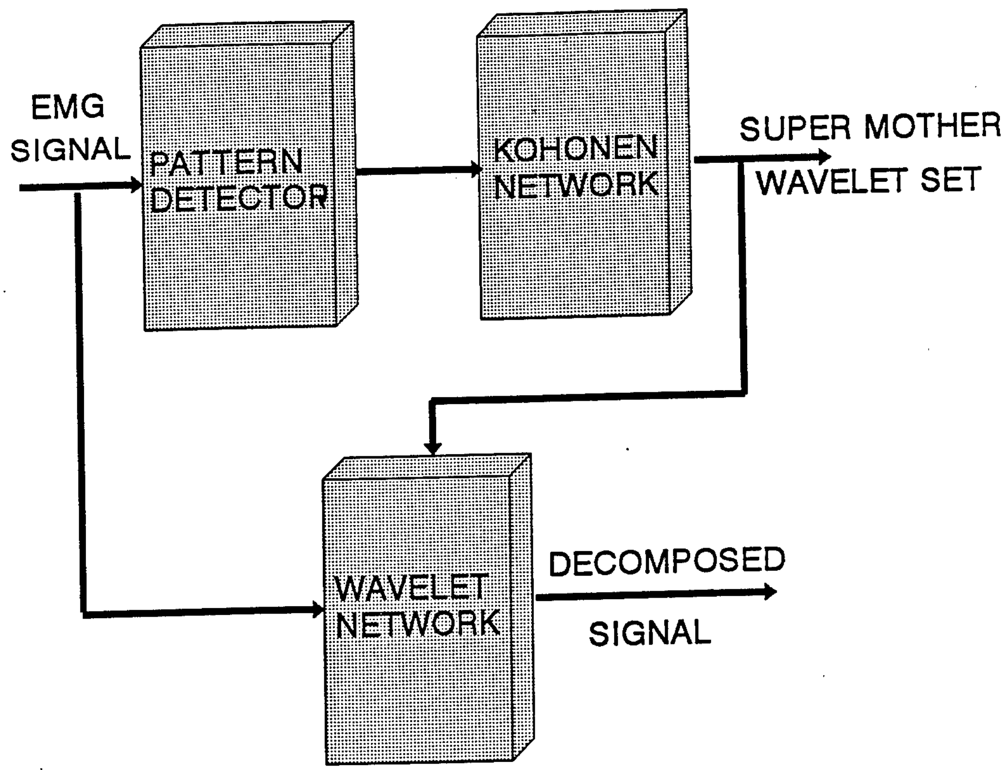


Figure 16: The proposed wavelet network-based decomposition.

4.4.4 Wavelet Network for Signal Decomposition

A possible use of wavelet network as shown in Figure 16 is proposed to replace the neural network once the mother wavelet (or a set of mother wavelets) is captured from the Kohonen neural network. In this wavelet network, each mother template will be used to find its scaled versions (during the motor unit recruitment process) which are a little dilated and shifted version of the mother wavelet. This distortion occurs to each mother Motor Unit Action Potential (MUAP) during a dynamic muscular contraction or due to fatigue during constant force muscular contraction. The distorted mother wavelets will be captured by a linear superposition of this wavelet network by, e.g. during a backprop least-mean-square (LMS) training phase. The Kohonen network will thus only be used for preprocessing to detect the number of classes and capture the mother wavelet set, download to the backprop wavelet network, to discover the super mother wavelet, and then bypass the Kohonen network and use wavelet network for real-time clinical application, similar to phoneme-super mother for complex speech classification by Szu et. al. [6].

4.4.5 Results and Conclusions

From the simulated signal, with 20% added noise, the network has decomposed and classified all the spikes correctly into their respective motor channel which is shown in the Figure 15. The system has performed with a success rate of 100%. The system has also performed successfully to identify the number of classes and to accommodate the network size and readjusting the network weights accordingly. In this experiment, the prototype templates could also be adaptively updated each time a new action potential is detected and use that

updated template to update the network weights. This would allow the stored template to adapt the gradual changes during the MUAP recruitment.

The EMG signal decomposition is very important for clinical neurologist for diagnosis of various neuro-muscular abnormalities such as neuropathy, myopathy etc. The firing patterns of individual motor unit can also be used for the study of biological motor control (neuro-control) strategies. The decomposition of neuro-muscular signal using an unsupervised Kohonen clustering network is a success experiment and can be easily implemented for on-line application. The major advantage is that one does not need to know the number of classes ahead of time in the signal. The size of the network updates as the system identify a pattern as new class.

References

[1] M. Bodruzzaman, "Development of on-line methods for analyzing clinical electromyographic (EMG) signal during dynamic muscle contraction," Ph. D. dessertation, Vanderbilt University, May 1990.

[2] M. Bodruzzaman, et.al., "Neuromuscular signal decomposition and prosthesis control using Hopfield neuro-chip," Proc. World Congress on Neural Networks (WCNN), Vol. 3, pp. 254-260, June 1994.

[3] T. Kohonen, "The Self-organizing Map," Proc. IEEE, Vol. 78, No. 9, pp. 1464-1480, September 1990.

[4] T. Kohonen, Self-Organization and Associative Memory, 2nd. edn. Springer-Verlag Publishing Co., Berlin, 1988.

[5] J. M. Zurada, Introduction to Artificial Neural Systems. West Publishing Co., St. Paul, MN, 1992.

[6] H. Szu, B. Telfer and S. Kadambe, "Neural network adaptive wavelets for signal reoresentation and classification," Optical Engineering, Vol.31, No. 9, pp. 1907-1916, September 1992.

4.5 Research Activities of Dr. Saleh Zein-Sabatto

Dr. Zein-Sabatto conducted research in following areas:

4.5.1 Behaviour Modeling of Biologically Motivated Neural Networks

In this research effort conducted under the CNE the relationship between a pre and post synaptic activities were modeled. The response of EPSP was modeled in order to provide more understanding of the time delay between the pre-synaptic stimuli and the post-synaptic response. The goal of this research is to model the time delay between the two signals and

possibly uncover the effects of such a delay, if any, on the learning that takes place in the Hippocampus. This research topic resulted from consortium formed between TSU/CNE and MMC. Recorded data were provided by MMC on video tapes, converted by CNE research into floppy disk and used in the modeling of the relationship between the pre and post-synaptic activities. A neural network was trained to model the post-synaptic response of population neurons from the Hippocampus. The neuro-model seems to learn exactly the measurable part of the EPSP response and predict the unmeasurable part of the response with acceptabl accuracy.

4.5.2 Neural Network Applications in Intelligent Flight Control Systems

The model helicopter XL-30 purchased in the summer of 1994, is assembled, tested and now is operational. A microcontroller system was designed built and tested on the helicopter. The microcontroller system consist of one master Stamp microcontroller for communication and five other Stamp microcontroller for actuator controls. The master microcontroller provides communication between a host computer and the actuator microcontrollers. The master microcontroller receives flight commands from the PC through its keyboard and sends them to the proper microcontroller connected to the target actuator. Figure 17 shows the schematic layout of the microcontroller system architecture. The next step for completing the control system is to equip the helicopter with sensor for feedback signals. Currently, the helicopter is equipped with one gyroscope providing information about the yaw axis of the helicopter. Two more gyros for the pitch and roll will be added to the helicopter. In addition, two pots will be added to the stand to provide information about the helicopter altitude and position in the horizontal plane. The established feedback signals will be measured and fed back to the PC through a additional stamp microcontroller where it will be used by an intelligent neurocontroller. The current hardware setup of the helicopter and its PC interface is shown in Figure 18.

4.6 Research Activities of Dr. Sanika Chirwa

Dr. Chirwa conducted research in the following area:

4.6.1 Motor Functions and EEG

The studies now permit recording of motor reflexes, EEG, EMG and locomotion. For this purpose, guinea pigs are anesthetized using sodium pentobarbital (40 mg/kg). The animals are then secured in a stereotaxic unit for placement of electrodes and/or brain infusion apparatus using osmotic pumps. For example, using bregma as a reference point, an L-shaped cannula is typically placed in the lateral ventricle using the coordinates 1.4 mm lateral- medial, 0.5 mm anterior - posterior, and 5 mm dorsal-ventral. The ALZET osmotic pump contain up to an 8-day infusion regime of saline, or any other drug of interest. Following the placement of the brain infusion apparatus, stainless steel screw electrodes are placed over the sigmoid gyrus to monitor EEG activity. The electrodes are cemented in to the position and their insulated wires are soldered to female connectors which are then affixed to the

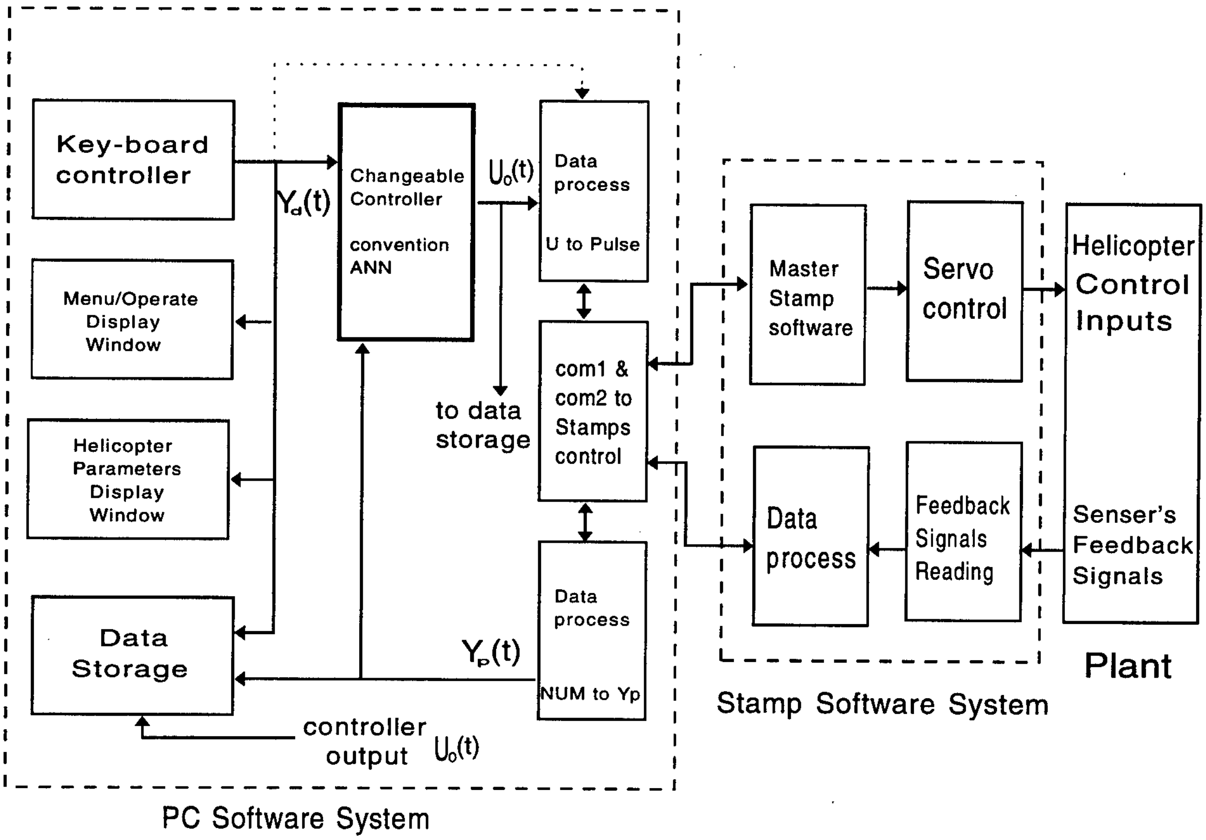


Figure 17: Schematic layout of the microcontroller system architecture.

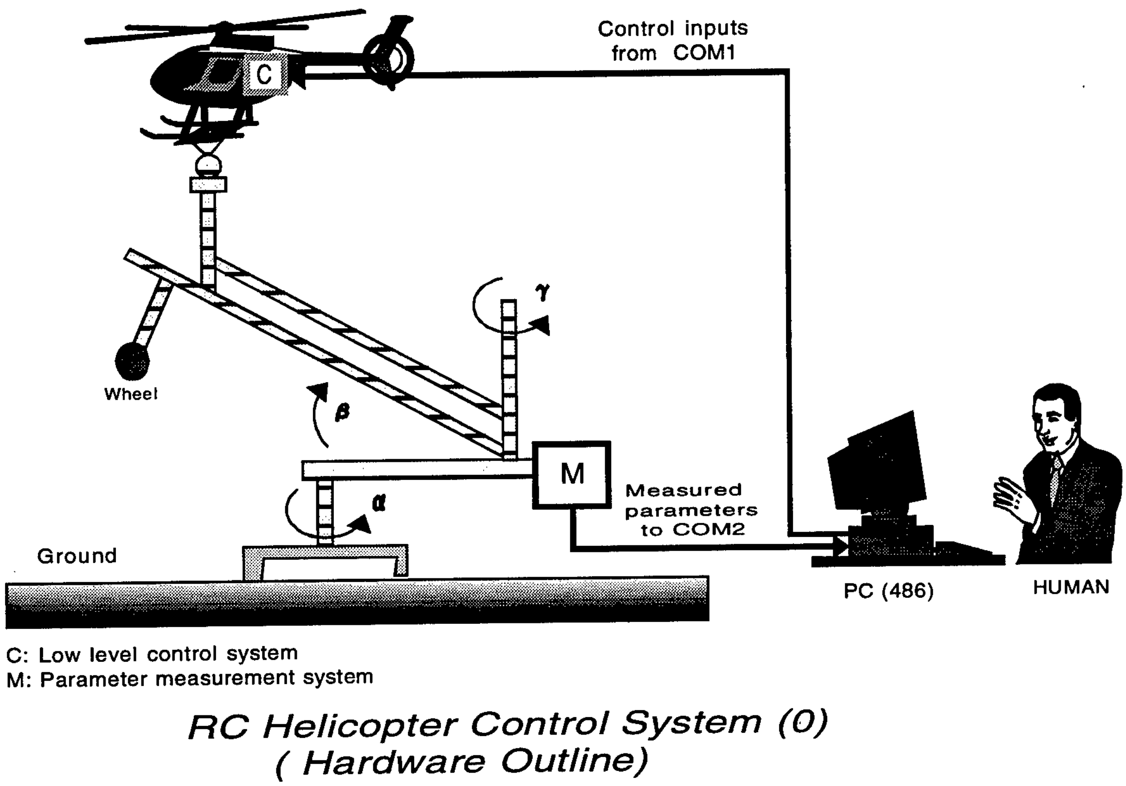


Figure 18: Helicopter hardware and PC interface.

calvaria with acrylic resin. The incision around the inserted osmatic pumps, if present, are closed with sutures and each animal is allowed a minimum of three days to recover post-surgery.

4.6.2 Assessments

Following surgical recovery each animal is given a number of tests to determine if motor function and EEG undergo any changes as a result of various research protocols. These tests are conducted for 15-30 minutes each day, over 7-12 day period. Each guinea pig is allowed to roam freely in a 2' X 2' observation box. After the animal is properly situated, the following tests are done; (a) domicility, (b) hindlimb extension, (c) startle (d) tremor (e) inclined screen, (f) righting reflex, and (g) stance 41. Therefore, each guinea pig is held in a stereotaxic frame via a modified headholding method which does not plug the animals' ears. After the animal is properly situated in the set-up, recordings of spontaneous sigmoid EEG and EMG are recorded and examined for presence of normal and abnormal wave patterns.

4.6.3 Cell Membrane Biophysics

After completion of the behavioral studies, animals are sacrificed 7-12 days post implementation surgery. Briefly, the brain is excised free and hippocampi are separated out and transferred to cold (4 Deg. C) and oxygenated artificial cerebrospinal fluid (ACSF; Composition in mN: $Nacl$, 120; 3.1; $NaHCO_3$, 26; $NaH2PO_4$, 1.3; $CaCl_2$, 2.0; $MgCl_2$, 2.0; and glucose, 10.0; pH, 7.4). One hippocampus is preserved for historical studies. The other hippocampus is sectioned transversely, at an angle of 70o to the midline (in order to preserve a greater percentage of Schaffer collaterals-commissural (Sch-comm) axons terminating in the same plane with the CAlb cells), at a thickness of 400 μm. The hippocampal sections are submerged in the cold oxygenated ACSF. Approximately 8 slices are selected from the middle portion of the hippocampus and transferred to the slice chambers and used in recordings. The main component of the slice chamber include (1) a circular well with drainage, (2) temperature control, (3) illumination, and (4) inlets for carbogen and ACSF. Solution flow to the slice chamber is by specialized pump feed (adjusted to a flow rate of 2-3 ml/min).

For recording purposes, extracellular responses are amplified with the 2-channel AC differential pre-amplifier. Intracellular responses are fed into an Axoclamp-2A; probe has an input resistance of 10^{10} Mohm with an input bias current of 0.5-1 pA, adjustable to zero at probe. Square wave pulses are delivered through photoelectric current isolation units regulated by the Grass S8800 stimulator. The amplified voltage potentials are fed into the digital Pulse Command Modulator recording adapter and taped onto a Video Cassette Recorder system. The taped signals are digitized at the rate of 10-20 microsec/bin and transferred onto a 486/33 Mhz computer for off-line analysis. Fiber filled borosilicate glass micropipettes pulled to fine tips (tip diameter, $1 - 2\mu$m) are filled with saline and used for recording field potentials. Micropippettes for intracellular recordings (tip diameter $< 0.5\mu$m) are filled with 3 M potassium chloride or potassium acetate. Thereafter, passive and active properties are recorded from the CA3-CA1 area of the hippocampus. Various experimental paradigms, which include examination of synaptic plasticity phenomena, are performed.

4.6.4 Single Cell Staining

At the completion of the selected intracellular recordings, cells are filled with biocytin with depolarizing current pulses (1-3 nA, for 1-3 min). Only one cell is filled in each slice. Slices are then transferred to 4% Zambonis paraformaldehyde in 0.1 M phosphate buffer (pH, 7.4). Slices are incubated in 0.3% hydrogen peroxide and 0.4% triton X-100 to both quench endogenous hydrogen peroxide and to permeabilize the cells. Thereafter, slices are incubated with avidin-biotin–horseradish complex and 4% triton X-100 in phosphate buffer saline for at least 2-hours. This is followed by reacting slices with diaminobenzidine in 0.1% hydrogen peroxide and 0.1% M tris (hydroxymethlyl) aminomethane buffer. This is done to visualize biocytin filled cells. Slices are then dehydrated in graded alcohols, cleared in xylene, and mounted onto chrome-alum gelatin slides. The process of each stained cell are traced with a camera lucida using a 40X oil immersion objective. A profile of the soma-dendritic tree is reconstructed from the drawings of the apical and the basal projecting dendritic trees. A 100X objective is used to inspect and draw the details of interest, as appropriate. A 3-D representation is re-created by computerized morphometry, whereupon a digitizing tablet is produced where the above drawing is traced. Computer software is used to calculate a variety of individual cell geometric parameters (i.e., soma surface area, soma perimeter, maximal and minimal diameter, etc.).

4.6.5 Cellular Morphology

Histological observations are used to aid in the visual differentiation of structure and size (which in turn, are correlated to electrophysiological data). Changes in the morphology in the cell body and axons, as well as alterations in cell densities which may occur as result of LTP induction, electrophysiological manipulations, chronic drug treatment, etc. The hippocampus reserved for the histological studies is incubated in Zamboni's 4% paraformaldehyde fixative. Following fixation the tissue are submerged in 20% sucrose in 0.1% M phosphate buffer saline (PBS; pH of 7.4) to cryoprotect the tissue. Once the tissue is infiltrated with sucrose, it is quick frozen in powdered dry ice and mounted on a cryostat chuck. The tissue is then sectioned at 15- 30microm and melted onto gelatinized slides. These sections are stained using the Nissl staining method. The section is mounted using permount and viewed using Carl Zeiss light microscope. The results from this procedure are used to examine the morphology of the cell within the hippocampus and any alteration in structure which may take place. In addition, sections are allowed to air dry overnight at room temperature. Thereafter, slides are rinsed in deionized water (dHOH), submerged in 0.05% potassium permanganate solution (consisting of equal portions of 1% hydroquinone and 1% oxalic acid) for at least 2 minutes or until the sections become clear. The slides will be rinsed thoroughly in dhoh. The slides are then incubated in a mixture containing 0.5% lead nitrate, 1.5% silver nitrate, and dHOH for at least three hours. Following this the slides are then placed in another solution containing 0.5% lead nitrate and 1.5% silver nitrate for one hour. The slides are then rinsed in dHOH and then transferred to ammonical silver nitrate solution for approximately three minutes. The sections are drained slightly and placed in Nauta-Gygax reducing solution for approximately 30 seconds and then placed in 0.5% sodium thiosulfate. The sections are dehydrated using a series of alcohol washes and xylene. The sections

may then be countersigned using the above Nissl staining procedure (optional) and dried overnight and mounted with permount: Xylene.

4.6.6 Data Analysis

Lastly, standard control procedures, with blinding wherever applicable, from the protocol of all experiments. Type I and II errors are restricted to 0.05 and 0.1, respectively. Two - tailed, paired tests are employed, unless one tailed, paired tests are required where the hypothesis specifies the direction of the differences. Students t-test are used for comparison between two related samples. One way ANOVA are used in comparisons among a series of means for which there is one criterion of classifications. If statistical difference are indicated, then Duncans' Multiple Comparisons tests is a posteriori test applied to detect the pairs of means presenting with statistical differences.

Data interpretation takes into account the following basic facts. Nerve cells generate electrical signals by changing the permeability of their membranes and allowing ions to diffuse down existing electrochemical gradients. Ionic fluxes generate current flows, and this alters membrane voltages in accordance with Ohm's law. Consequently, neurons can be described in terms of equivalent electrical circuits consisting of batteries, resistors and capacitors. This model provides a method for assessing the biophysical properties of neurons, and this is utilized in this project.

5 Faculty Publications

The faculty publications increased significantly over first year list of six publications as shown below:

1. J. G. Kuschewski, S. Hui, and S. H. Zak, "Analysis and design of integral controllers for discrete systems," *Proceedings of the 32nd annual allerton conference on communication, control, and computing*, Monticello, IL, September 28–30, 1994, pp. 31–40.

2. S. Zein-Sabatto, M. Bodruzzaman, and J. G. Kuschewski, "Biologically motivated servomechanism kinematic models," *Proceedings of the 1995 IEEE Southeastcon Conference*, Raleigh, NC, March 26–29, 1995, pp. 165–168.

3. J. G. Kuschewski and S. Zein-Sabatto, "Discrete dynamic system parameter identification and state estimation using a recurrent neural network," *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

4. J. G. Kuschewski, S. Hui, and S. H. Zak, "Fuzzy integral control of discrete dynamic systems, Parts I and II," *Submitted for publication in the IEEE Transactions on Industrial Electronics.*

5. G. L. Yuen, P. E. Hockberger and J. C. Houk "Bistability in cerebellar purkinje cell dendrites based on high-threshold calcium and delayed- rectifier potassium channels" Biological Cybernetics, in press, 1995.

6. W. R. Hwang, J. G. Kuschewski, G. L. Yuen, and S. Zein-Sabatto, "Reinforcement learning controllers for dynamic systems," *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

7. G. L. Yuen and C. Keaton, "Dynamic current-voltage characteristics in neuronal dendrites," *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

8. S. Zein-Sabatto, W.R. Hwang, and J.G. Kuschewski, "Neuro-observer for aircraft state reconstruction," *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

9. T. Robinson, M. Bodruzzaman, K. Preddy and K. Mathia, "Real-time stable adaptive control inplementation using a neural network processor." *Proceedings of SPIE'95 Conference*, Miami, FL., April 1995.

10. M. Bodruzzaman, S. Zein-Sabatto, O. Oluwole, M. Malkani and H. Szu "Electromyographic (EMG) signal decomposition using Kohonen neural network and wavelet network." *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

11. T. Robinson and M. Bodruzzaman, "Adaptive filtering using Youla parameterization and neural network." *Proceedings of World Congress on Neural Networks (WCNN'95) Conference*, Washington D.C., July 17-21, 1995.

12. M. Bodruzzaman, "Neural network-based modeling of pressure-drop data obtained from fluidized bed combustion system," *Proceedings of 3rd Annual HBCU/Private Sector/DOE R&D Technology Transfer Symposium*, Atlanta, GA, April 29, 1995.

13. E. Floyd, A. Eeaton, J. Clark and H. Rucker, "Chronic ethanol ingestion alters parameters of mid-latency auditory evoked potentials in male rats," J. Pergamon. 0741-8329(94), 00061-2,1994.

14. H. Rucker, E. Floyd, W. Thomas, and E. Moore, "Modulation of pedunulopontine tegmental nucleus and alterations in glutamate-evoked discharge rate of nucleus ambiguous cholinoceptive neurons in rats". Lung Bro Health Dis. 82: 237-252, 1995.

15. S. Chirwa and M. Clayton, "Direct effects of methamphetamine on glutamatergic neurons." Soc.Neurosci. Vol. 20, pp. 1287, 1994.

16. E. Onavi, K. Parker, A. Chakrabarthi, G. Chaudhuri, E. D. Mutley, C. Bishop-Robinson, S. Chirwa, "Neurobiological bases of methamphetamine action in the hippocampus." Soc. Neurosci. Abstr. vol. 20, pp. 1287, 1994.

17. E. Onavi, K. Parker, C. Bishop-Robinson, A. Chakrabarthi, G. Chaudhuri, E. Mutley, S. Chirwa, "Neurobiological of the action of cocaine in the hippocampus," FASEB J. vol 9, A401, 1995

18. A. Blackshear "Acute and chronic effects of M-chlorphenylpiperazine on food intake and brain $5-HT_2$ and $5-HT_{1b}$ binding sites." Soc. for Neurosci. Abs. 20:634. 14, 1994.

6 Faculty Presentations

1. Dr. Yuen gave tutorial lectures for CNE members on [1] LTP learning models (Stable Presynaptic learning) and [2] The Phone-recognition problem and its relevance for Speech Recognition.

2. Dr. Yuen gave the lecture "Engineering Intelligent Systems with Neurobiology" for monthly research series of Vanderbilt University's Center for Intelligent Systems and TSU's Center for Neural Engineering, March 1995.

3. Dr. Yuen presented "Dynamic current-voltage characteristics in neuronal dendrites" at the World Congress on Neural Networks (WCNN), Washington, D.C., July 17-21, 1995.

4. Dr. Kuschewski presented "Analysis and design of integral controllers for discrete systems", 32nd Annual Allerton Conference on Communication, Control, and Computing, Monticello, IL, September 28–30, 1994.

5. Dr. Kuschewski presented "Discrete dynamic system parameter identification and state estimation using a recurrent neural network," 1995 World Congress on Neural Networks (WCNN), Washington, D.C., July 17–21, 1995.

6. Dr. Bodruzzaman presented "Electromyographic (EMG) signal decomposition using Kohonen network and Wavelet network." 1995 World Congress on Neural Networks, Washington DC. July 17-21, 1995.

7. T. Robinson presnted "Real-time stable adaptive control implementation using a neural network processor." SPIE'95 Conference, Miami, FL., April 1995.

8. T. Robinson presented "Adaptive filtering using Youla parameterization and neural network." 1995 World Congress on Neural Networks, Washington D.C., July 17-21, 1995.

9. Dr. Zein-Sabatto presented "Biolgically motivated servomechanism kinetic models." IEEE Southeastcon '95 Conference, Raleigh, NC., March 26-29, 1995.

10. Dr. Zein-Sabatto presented "Neuro-observer for aircraft state recognition." 1995 World Congress on Neural Networks, Washington D.C., July 17-21, 1995.

11. Dr. Blackshear presented "Acute and chronic effects of M-chlorphenylpiperazine on food intake and brain 5-HT2 and 5-HT1b binding sites. Soc. for Neurosci. Abs. 20:634. 14, 1994.

7 Technology Transfer

7.1 STTR: Technology Transfer Research Project. Principal Investigator: Dr. Saleh Zein-Sabatto.

Tennessee State University with Mid-South Engineering Company under STTR submitted a technology transfer proposal on **"Spherical motor and neurocontroller for micro-precision robot wrist"** to NASA under the catagory of Robotics. NASA reviewed 72 proposals and funded only 7. Tennessee State University shared the honor with Jet Propulsion Laboratory, University of Michigan, Stanford Research Institute, University of Southern California, State University of New York at Buffalo and the University of California at Berkeley.

In this project a spherical motor with an artificial neural network controller was proposed for use as a micro-precision robot wrist. With the proposed spherical motor, roll, pitch, and yaw motion are combined in a single joint. The direct drive, 3 axes spherical motor eliminates blacklash and friction due to gear meshing. In addition to its compact design, the proposed spherical motor results in simple joint kinematics and has no singularities in its working envelop. The 3-dimensional array of stator coils are driven by the proposed neural network controller in response to specified roll, pitch and yaw values. Motor resolution is controlled by a combination of coil design and distribution in the stator, fine serration of the stator and rotor surfaces, and multiple pulse combinations delivered to the stator coils from the neural network controller. The single joint design of the spherical motor lends itself to builtin wrist force/torque sensing and control. The proposed artificial neural network controlled spherical motor has great potential commercial application in all robot requirements for high speed precision end-effector manipulation of orientation with continuous motion in all directions. The precision control coupled with the spherical motor's compact design makes it particularly appealing for applications in confined spaces. Figure 19 shows a 3-D view of the initial motor design completed for phase I of the research.

8 Participation in Proposals

The Center faculty participated actively in submitting proposals to various agencies as follows:

1. "Vibration and motor current signature analysis." Principal Investigator: Dr. M. Malkani. Agency: Facility Management Organization (FMO): Y-12 Plant, Martin Marietta Energy Systems (MMES), Oak Ridge, TN. Total Amount: **$80,000** for 1 year. Period: May 1995 - April 1996.

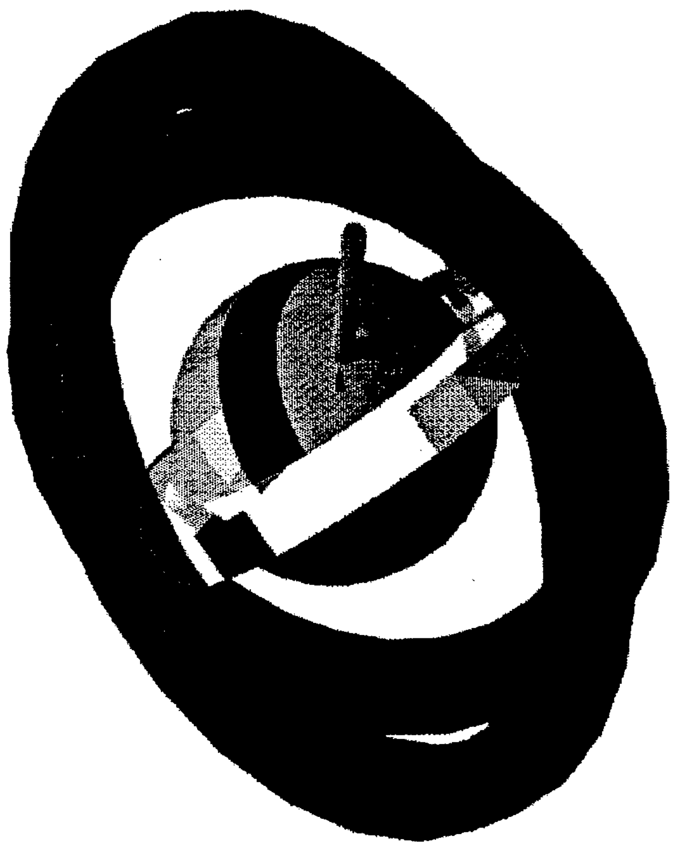


Figure 19: 3-D view of the initial motor design.

2. "Raytheon Federated Laboratories Industry/University Consortium." Principal Investigator: Dr. M. Malkani. Agency: Raytheon Company in response to US ARMY Research Laboratory, Total Amount: **$2.53 Million** for 5 years. February 1995.

3. "Renewal for Center for Neural Engineering." Center Director: Dr. M. Malkani. Agency: Office of Naval Research (ONR), Washington D.C. Total Amount:**$1.5 Millions** for 3 years. February 1995.

4. "Center for Scientific Foundations of Image Analysis." Principal Investigator: Dr. M. Bodruzzaman. Agency: UT-Knoxville in response to the BAA of US ARMY Research Office, NC. Total Amount: **$1.6 Million** for 5 years. April 1995.

5. "Medical Federated Laboratory: Telemedicine." Principal Investigator: Dr. M. Bodruzzaman. Agency: IIT, Chicago, IL, in response to U.S. Army BAA: DAMD17-95-#-0011. Total Amount: **$600,000** for 3 years. June 1995.

6. "Software and Intelligent Systems." Principal Investigator: Dr. M. Malkani. Agency: Motorola Co., in response to US ARMY Research Laboratory. Total Amount: **$1.5 Million** for 3 years. April 1995.

7. "Neural network applications for MAGLEV system controls." Principal Investigator: Dr. S. Zein-Sabatto. Agency: Northrop-Grumman, in response to ARPA Technology Reinvestment Program. Total Amount: **$183,980** for 2 years. February 1995.

8. "Advanced Hardware for Implementation of Neural Networks" Department of Defense (DOD). Objective: to improve the CNE's ability to perform hardware neural network simulations and demonstrations of real-time plausibility of concepts. Principal Investigator: Dr. G. L. Yuen. Award Amount: **$47,500**. November 1994.

9. "Nonlinear Dynamic Computation in Cerebellar Purkinje Cell dendrites" Principal Investigator: Dr. G. L. Yuen. Agency: Office of Naval Research (ONR). Total Amount: **$60,000** for 1 year. February 1995.

10. "Learning of non-unique mappings and application to control" Principal Investigator: Dr. S. Zein-Sabatto. Agency: NASA (Lewis).

11. "Computer Hardware Improvement Instrumentation Proposal for the CNE", Principal Investigator: Dr. J. G. Kuschewski. Agency: DoD. Total Amount: **$7,341** for 1 year. November 1994.

9 Faculty Self Improvement Activities

9.1 Activities of Dr. Yuen

1. Attended the Neural Information Processing Systems (NIPS) Conference, Denver/Vail, Colorado, November 1994.

2. Attended monthly research series meetings between Vanderbilt University's Center for Intelligent Systems and TSU's Center for Neural Engineering.

3. Arranged for Professor Timothy Teyler's various visits to develop collaborative projects and delivery of the Distinguished Lecture Series talk entitled "Multiple Forms of Synaptic Plasticity in Hippocampus" April 1995.

4. Visited Professor Timothy Teyler's laboratories in Ohio for collecting literature, consolidating research projects and acquired experimental data in April 1995.

5. Attended the 1995 World Congress on Neural Network (WCNN'95) Conference, Washington D.C., July 17-21, 1995.

9.2 Activities of Dr. Kuschewski

1. Attended the 32nd Annual Allerton Conference on Communication, Control, and Computing, Monticello, IL, September 28–30, 1994.

2. Attended monthly research series meetings between Vanderbilt's Center for Intelligent Systems and TSU's Center for Neural Engineering.

3. Attended the 1995 World Congress on Neural Networks (WCNN'95), Washington, D.C., July 17–21, 1995.

4. Served as chairman of a subcommittee and a member of the Agenda 2000 Information Technologies Committee that is responsible for addressing computer infrastructure improvement in TSU's research and teaching environments.

9.3 Activities of Dr. Zein-Sabatto

1. Attended IEEE Southeastcon '95, Raliegh, NC, March 26-29, 1995.

2. Chaired a session in Neural Networks at IEEE Southeastcon '95, Raliegh, NC, March 26-29, 1995.

3. Attended the 1995 World Congress on Neural Networks (WCNN '95), Washington DC., July 17-21, 1995.

4. Organized and attended monthly lecture series for researchers from TSU and Vanderbilt Universities.

9.4 Activities of Dr. Bodruzzaman

1. Reviewed a STTR grant proposal on "Applications of Neural Networks to Implement of NOx Monitoring and Heat Rate in Fossil-Fueled Power Plants." (Grant Application No.: 02173-95-I), reviewed for DOE, April, 1995.

2. Attended one day Symposium on Predictive Maintainance (PdM) Sponsored by DOE, April, 1995.
3. Attended two days conference on DOE sponsored conference on Advanced Coal-Fired Power Systems, at Morgantown, WV, June 26-29, 1995.
4. Attended the 1995 World Congress on Neural Networks (WCNN '95), Washington DC, July 17-21, 1995.

9.5 Activities of Dr. Blackshear

1. Attended the annual meeting for Soc. for Neuroscience Nov. 13-18, 1994, Miami, Florida.
2. Attended the Teaching and Learning Retreat sponsored by MMC in April 1995.
3. Attended workshop on Computer Aided Instruction in Physiology at the University of Louisville, Nov. 1994.

9.6 Activities of Dr. Rucker

1. Attended the Annual meeting for Soc. for Neuroscience Nov. 13-18, 1994, Miami, Florida.
2. Attended World Congress on Neural Networks, June 5-9, 1994, San Diego, CA.

10 Distinguished Lecture Series

Dr. Christopher Koch, Professor of Computation and Neural Systems at California Institute of Technology visited CNE and presented a seminar on "Towards a Neurobilogical Theory of Conciosness" on October 3, 1994. Recent experimental advances in the brain sciences enables us to approach the problem of conscious and unconscious from a rigorous scientific point of view. For instance, cognitive science has shown that human beings can store certain information in the brain and act on it without ever becoming aware of there memories. From clinical studies it is known the so-called "blind sight" patients with brain lesions can point to objects while strenously denying seeng them. Prof. Koch reviewed visual perception and memory in the context of our knowledge of nerve cells and the brain. He then discussed a theoretical progress which Francis Crick and he has developed to help us understand how the electrical activity of nerve cells in our cortex relates to attention, short-term memory and ultimately awareness.

Dr. Harold Szu, Group Leader, Information Science Division at Naval Surface Warfare Center and Member, Board of Directors of CNE presented an enlighting seminar on "Wavelet theory and its applications" on October 4, 1994.

Dr. Timothy Teyler, Professor of Neurobiology in the Northeastern Ohio College of Medicine, presented a seminar on "Multiple forms of synaptic plasticity in Hippocampus" on April 4, 1995.

10.1 Monthly Lecture Series

As a second spin-off of CNE, the researcher at Tennessee State University's Center for Neural Engineering and the researchers at neighboring Vanderbilt University's Center for Intelligent Systems met during Spring 1995 semester and agreed to share their resources and submit joint proposal for funding. To simulate the exchange of ideas it was agreed to immediately start monthly lecture series, and as a result the following lectures were delivered:

1. Dr. Gautum Biswas, Associate Professor of Compter Science at Vanderbilt presented a seminar on "Intelligent systems and environmentally conscious manufacturing" at TSU on February 24, 1995.

2. Dr. Geoffery Yuen, Research Associate at TSU/CNE presented a seminar on "Engineering intelligent systems with neurobiology" at Vanderbilt University on March 1995.

3. Dr. Mones Inkarous of VU/CIS presented a seminar on "Modeling and intelligent control using Fuzzy-Neuro Networks" at TSU on April 28, 1995.

The researchers both at TSU/CNE and VU/CIS toured each other's facilities and greater synergies are expected to be generated during 1995-96 school year.

11 Recruitment of Research Associates

The CNE hired two very competent Post-Doctoral Research Associates Dr. John Kuschewski and Dr. Geoffrey Yuen. John received B.S., M.S., and Ph.D. degrees from Purdue University. His research interests are in control, neural networks and fuzzy logic. Geoffrey received B.S. in Chemistry from Wheaton College, M.S., and Ph.D. degrees in Biomedical Engineering from Case Western Reseearve University. He has four years Post-Doctoral research experience at Northeastern University Medical Center. Both are valuable assets to the CNE.

12 Programs for Students

12.1 Student Recruitment Activities

We continue to recruit the students to conduct research in the Center for Neural Engineering as follows:

1. Announcement is posted on the College bulletin Board for graduating seniors with a GPA of at least 3.0 out of possible 4.0 to apply with a copy of transcript and a letter expressing their interest to conduct research at the Center. A student must agree to complete their senior project at the Center and that a student must set aside at least a block of three hours to conduct research.

2. Outstanding juniors are also involved in research and looked upon as potential candidates to generate a pipeline.

3. Undergraduate students are exposed to the field of neural networks through the distinguished lecture series program.

4. Demonstrations are being set up in the Center to motivate the students in this technology.

5. Recruitment poster and related literature is sent our sister HBCU/MI institutions to recruit graduate students.

6. Announcement are placed at the national NSBE and SWE conventions.

7. The college also participates in Science and Engineering graduate recruitment fairs.

8. Announcement are sent periodically to other universities with engineering programs.

12.2 Summer Educational/Enrichment Programs

1. Carolyn Keaton, Tim Robinson and Jarvis Spruill attended the WCNN'95 conference at Washington DC, July 17-21, 1995. Tim Robinson presented a paper on "Adaptive filtering using Youla parameterization and neural networks" at this conference. Carolyn Keaton co-authored a paper with Dr. Yuen that was presented at the conference.

2. Tim Robinson will spend summer at CNE to complete Masters Thesis.

3. Carolyn Keaton, Vivian Doresy, and Jarvis Spruill will spend their summer at CNE. They will interact with MMC to collect data on their research.

12.3 Research Opportunities and Internships

All graduate research assistants are provided the opportunity to work half time (20 hours per week) during the school year and full time (40 hours per week) during summer. Undergraduate assistants can work a maximum of 10 hours per week during academic year and full time during summer. During the academic year research can be done at TSU and or MMC.

Due to our unique teaming arrangement, the students are provided the opportunity to spend either full or part summer at our consortium partners TSU, MMC, ORNL and AAC, thus proving a variety of experience to the student to enhance his/her professional development. This could lead to a challenging Master's thesis and a journal article.

Students attending at Meharry Medical College are exposed to basic electrophysiological techniques associated with the recording of bio-electric events from live animals to include protocol development, animal surgery, instrumentation, analysis as well as ethical and humane considerations. This program could be enhanced by pairing students on a long term basis with Ph.D. level neuroscience students working in this laboratory.

12.4 Mentoring Programs

Each research assistant is provided a TSU faculty member as a mentor. The mentor meets with the student at least once a week or more as the need may be. During summer months a student could have two mentors if he/she is spending summer at consortium partners facility. However a TSU faculty member will be the primary thesis advisor and this is made clear to consortium partners.

13 Facilities and Equipment

The Center of Neural Engineering in collaboration with a grant from NASA on Robust Integrated Neurocontroller now has eight (8) 486-based IBM compatible PCs, three (3) Pentium based PCs and two (2) HP laser printers. CNE has also purchased EKG, EMG and EEG recording equipments to enhance the research capabilities of the Center. A small model of helicopter is also acquired by the Center, since many students have shown interest in helicopter control system using neural networks. When fully implemented CNE will be able to show on line demonstration at all times.

14 Specific Program Objectives for Next Year

It is envisioned that with a greater interaction among consortium partners a well focused research will be conducted leading to quality research and journal papers. The specific objectives of various researchers are listed below.

14.1 Goals of Dr. Yuen

1. Complete and publish the following papers in the next 12 months : [i] Two papers related to the biophysical modelling of hippocampal granule cells and the NMDA-receptors based on work completed previously. [ii] One paper related to the dynamic regulation of current-voltage properties in Purkinje cells by calcium. [iii] One paper related to bidirectional control of synaptic modification using PKC. [iv] Other papers reporting on the results of these application projects: [a] 2-D pole balancing [b] Spatial-memory navigation and [c] Phone recognition. Comparing the performance of prototypical neural network to more traditional neural network designs (reinforcement learning and hybrid fuzzy-logic designs).

2. Continue advising graduate students for completion of Masters thesis research.
3. Focus on the the following two primary projects: [i] Development of the new neural network architecture using oscillatory neurons and frequency-dependent synaptic modification. [ii] Biophysical basis of dynamic, frequency-dependent synaptic modification rules.
4. Set-up CNE with a number of interesting application testbed problems to assess the potential of new neural network architecture(s) developed here and elsewhere.
5. Develop new student projects in digital signal processing (dsp) hardware implementation of new neural network architectures.

14.2 Goals of Dr. Kuschewski

Dr. Kuschewski will interact with Dr. William Bond and Mr. Barry Streeter of McDonnell Douglas Aerospace. His specific goals are as follows:

1. Generate 2 peer reviewed journal papers from current work.
2. Successfully complete the neural network aerodynamic data modeling project, and have the neural network model be chosen to be flight tested in an actual F-15 aircraft flight computer.
3. Continue developing the intelligent aircraft control system testbed.
4. Further develop and test for higher order systems the recurrent neural network based discrete dynamic system parameter identifier and state estimator.
5. Co-advise 2 graduate students.

14.3 Goals of Dr. Rucker

1. To generate 3 peer reviewed papers from current work.
2. To present work at 2 national symposia.
3. To mentor 2 students in biomedical data gathering.
4. To develop a model of cortical auditory processing based on primary data which includes bias weights representing diffuse cortical afferents.
5. To study state dependent acetylcholine release in cortex.
6. To offer the Advanced Neurophysiology course again in the Spring 1996 semester.

14.4 Goals of Dr. Blackshear

Working in collaboration primarily with Dr. Rucker, Dr.Blackshear's goals are as follows:

1. To continue increase knowledge of neural networks and auditory cortex simulation, as well as increase interactions with other faculty in the program.
2. To generate 2 peer reviewed papers from current research.
3. To present work at 2 national symposia.
4. To mentor TSU students in biomedical data gathering.
5. To develop a model of cortical auditory processing based on primary data which includes bias weights represented diffuse cortical afferents.
6. To again offer the Advanced Neurophysiology course.

14.5 Goals of Dr. Chirwa

1. Continue to expand laboratory research capabilities, add personnel.
2. Publish 2-4 full length research papers in peer-reviewed journals.
3. Secure 2-3 grant research funds.
4. Submit an R29 grant application to NINES.
5. Attend 2-3 scientific meetings including Society for Neuroscience.
6. Continue research collaborations at Meharry (Drs. Motley, Onaivi and Chakrabarti) and the Center for Neural Engineering at Tennessee State University.

14.6 Goals of Dr. Bodruzzaman

Dr. Bodruzamman will interact with Dr. Rucker and Dr. Bhattacharyyia at Meharry Medical College, Dr. Kevin Priddy at Accurate Automation Corporation and Dr. Chuck Glover at Oak Ridge National Laboratory. His specific goals for next year are as follows:

1. Generate 2 refereed, 1 journal and 3 conference papers with consortium partners from current works.
2. Mentor 2 undergraduate students in generating and supervising their senior project in the area of neural networks.
3. Mentor 2 graduate students in generating and supervising their Master's thesis in the area neural network applications.

4. Develop experiment and data acquisition system based EMG, EEG, and ECG measurements on MP100WSW system on PC.

5. Develop collaboration with Dr. Muhit Bhttacharyya, Professor of Physiology, Mehary Medical College in developing graduate and undergraduate research project in the area of Medical Diagnosis of Cardiac System using chaos and neural networks techniques.

6. Develop a new course on Image Processing and Neural Network Applications and laboratory experiments on neural network-based image processing.

7. Analyze auditory data for Eric Floyd and Dr. H. Rucker of Mehary Medical College for a possible publication.

8. Supervise one graduate student (Tim Robinson) to complete his Master's project this summer.

9. Teach graduate level neural network course (EE525) in the fall of 1995.

14.7 Goals of Dr. Zein-Sabatto

Dr. Zein-Sabatto will interact with Dr. Chirwa of MMC and Dr. Chuck Glover of ORNL. His specific goals are as follows:

1. Complete the Helicopter testbed project and start implementing neural network for modeling and closed-loop control of the Helicopter.

2. Continue the development of neurocontrol systems based on actual biological sensory motor control with application to spherical servomechanism.

3. Continue the development of the time delay between pre-synaptic and post-synaptic responses and provide results to MMC.

4. Mentor 3 undergraduate and develop senior projects for them in the neural network and control systems area.

5. Mentor 2 graduate students and develop two Masters thesis for them in the area of biological NN, modeling and control systems.

6. Publish journal articles jointly with MMC.

7. Implement the development of naviagation learning in the Hippocampus by Jarvis Spruill on real-world engineering problem.

8. Apply for patent on joint controller.

15 Consortium Interaction

15.1 Interacton between TSU and AAC

Accurate Automation Corp.(AAC) and the Center for Neural Engineering at Tennessee State University(TSU) cooperate on the following, current or future, research project and joint efforts.

AAC staff and faculty members of the College of Engineering and Technology at Tennessee State University, conduct joint research projects and publish results of these joint efforts via co-authored papers. For the purpose of efficiency, TSU faculty and AAC staff share data from experiments a well as operating systems, for example from helicopters and other aircraft. Data and Hardware/Software are supplied by both AAC and the Center for Neural Engineering for improved research efficiency.

Senior staff of Accurate Automation Corp. participate as members of thesis advisory committees of graduate students at TSU. Currently Dr. Priddy is on the committe of Timothy Robinson, who is conducting his masters thesis research at AAC. This situation is ideal from a research point of view, with communication between Timothy Robinson and Dr. Priddy occurring on a daily basis. Timothy joined the software engineering team at AAC, and is developing modules for the software environment of the AAC Neural Network Processor (NNP), as well as assembler programs for the NNP itself. Dr. Richard Saeks and Dr. Kevin Priddy of AAC are also listed as Adjunct Graduate Faculty in TSU Graduate Catalog.

15.2 Interacton between TSU and ORNL

Oak Ridge National Laboratory (ORNL) was involved in collaborative research efforts with all Center of Neural Engineering (CNE) partners during this reporting period. In addition, ORNL also provided assistance in establishing new research initiatives and collaborations, in evaluating and selecting candidates for new post doctoral positions, and in establishing new links between CNE and outside organizations.

Research collaborations exist between ORNL and each of the CNE institutions. Dr. Glover is working with Drs. Chirwa (MMC), Bodruzzaman (TSU), and Zein-Sabatto (TSU) to provide a model of neural interactions in the hippocampus. This model should provide new insight into the time-dependency of the onset of long term potentiation (LTP). Furthermore, this will be used in a new design of an artificial neural network (ANN) model. In addition, Bridgette Bundridge (TSU graduate student) is worked with Dr. Glover on an ANN algorithm to track multiple objects in a cluttered environment. The tracking algorithm is based on a model of motion detection in the retina. This research which has been supported by both the CNE and ORNL, makes use of ORNL's unique computing capabilities. This work has resulted in a Master's thesis. Dr. Glover has also collaborated with Dr. Rucker (MMC) on the possibility of making spatio-temporal measurements of neurons in the auditory cortex of a motivated and trained rats. By measuring the spatio-temporal response during sound recognition and comparing it with measurements made during the

resting state, the neurodynamics of pattern recognition in the auditory cortex can be studied and compared to similar studies in the olfactory and visual cortexes. Finally, Dr. Glover has worked with Accurate Automation Corporation (AAC) researchers in developing techniques to model nonlinear systems from the analysis of these system's signals.

The Predictive Maintainance Division at Y-12 Manufacturing Technology Center at the Oak Ridge Complex invited CNE researchers to present their work on ANN system dignostics at a meeting in Atlanta in May 1994. This has lead to exploratory funds for CNE to establish a new collaborative initiative between Y-12 and engineering faculties and students. Finally, ORNL has participated with CNE management in interactions with several industrial organizations.

PART II

16 Information on Seniors and Graduate Students in The Program

During the school year 1994-95 a total of nine (9) seniors participated in the Center of Neural Engineering. They conducted research on various topics under the supervision of faculty mentors. Four (4) student projects were funded by NASA and five by ONR under this grant, six students completed their research projects which generated into senior projects and other two will complete their project during the academic year 1995-1996.

The names of the students, their major field of study, their faculty mentor, the name of their graduate school or their employer upon graduation, and their project title is listed below:

16.1 Undergraduate Students

1. Edna Jones
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Bodruzzaman
   - Date of Graduation: August, 1994
   - Graduate School: Tennessee State University
   - Employer:
   - Project Title: Chaotic Hardware and Neural Network Modeling
2. Stephanie Smith
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Bodruzzaman
   - Date of Graduation: May, 1995
   - Graduate School:
   - Employer: Motorola
   - Project Title: Neural Network Based Prosthesis Control
3. Tretessa Johnson
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Zein-Sabatto
   - Date of Graduation: May, 1995
   - Graduate School:

- Employer: Motorola
- Project Title: Neuron Model for Plausible Neural Network Design

16.2 Graduate Students

1. Bridgitte Bundrage
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentors: Dr. Malkani (TSU), Dr. Glover (ORNL)
   - Date of Graduation: May, 1995
   - Graduate School: Tennessee State University
   - Employer:
   - Thesis Title: Neural Network Approach to Tracking Multiple Objects
2. Richard Griffin
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Bodruzzaman
   - Date of Graduation: December, 1994
   - Graduate School: Tennessee State University
   - Employer:
   - Thesis Title: Binaural Sound Localization Using Artificial Neural Networks
3. Carolyn Keaton
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentors: Dr. Yuen (CNE), Dr. Bodruzzaman (TSU), and Dr. Chirwa (MMC)
   - Date of Graduation: December, 1995 (expected)
   - Graduate School: Tennessee State University
   - Employer:
   - Thesis Title: Training Oscillatory Neurons With a Frequency-Dependent Learning Rule
4. Timothy Robinson
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentor: Dr. Bodruzzaman (TSU), Dr. Priddy (AAC)
   - Date of Graduation: August, 1995
   - Graduate School: Tennessee State University

- Employer:
- Thesis Title: Stable Adaptive Control Utilizing Artificial Neural Networks

5. Vivian Dorsey
   - Major Field of Study: Electrical and Computer Engineering
   - Faculty Mentors: Dr. Zein-Sabatto (TSU), Dr. Kuschewski (CNE)
   - Date of Graduation: August, 1996 (expected)
   - Graduate School: Tennessee State University
   - Employer:
   - Research Title: Design of Artificial Limb Using Spherical Joints

17 Additional Data

A list of graduated students and their current status are given below:

1. Ronnie Harper
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: December, 1992
   - Employer: General Motors Corporation
2. Lamar Crowder
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Employer: Delco Electronics (GM)
3. Wayne Garrison
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Employer: International Paper
4. Anthony Wilson
   - Major Field of Study: Electrical Engineering
   - Date of Graduation: May, 1993
   - Graduate School: Georgia Tech
5. Mario Yancy
   - Major Field of Study: Electrical Engineering

- Date of Graduation: May, 1994
- Graduate School:

6. Lisa Callway
    - Major Field of Study: Electrical Engineering
    - Date of Graduation: May, 1994
    - Graduate School: Prairie View A&M University

7. Vivian Dorsey
    - Major Field of Study: Electrical Engineering
    - Date of Graduation: May, 1994
    - Graduate School: Tennessee State University

8. Edna Jones
    - Major Field of Study: Electrical Engineering
    - Date of Graduation: August, 1994
    - Graduate School: Tennessee State University

9. Bridgitte Bundrage
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: May, 1995
    - Employer: Raytheon Corporation

10. Richard Griffin
    - Major Field of Study: Electrical Engineering (M.E. Degree)
    - Date of Graduation: December, 1994
    - Employer: Tennessee State University

18. Enrollment and Academic Performance Data

Table 2: Enrollment data.

	Number of students enrolled at school (by year) Fall 1994				Number of students enrolled in ONR program (by year)				Number of students graduated Aug.'94 & May'95		Number to Graduate or Professional School	
Major Discipline (Science Engineering)	1 Fr.	2 Sph	3 Jr.	4 Sr.	1 Fr.	2 Sph	3 Jr.	4 Sr.	Total	ONR	Total	ONR
Biology	101	70	78	82				1	29		10	
Chemistry	22	19	10	19					12		6	
Computer Science	81	54	43	71					36		6	
Engineering	260	128	118	225		42	1	4	58		12	3
Mathematics	12	12	10	15					8		2	
Physics	3	1	2	2					1		1	
Totals for science and engineering	479	284	261	414		4	1	5	144		37	3

Table 3: Academic performance data.

Class Year	Mean SAT (ACT) for all Freshmen	Mean SAT (ACT) for ONR Freshmen	Mean GPA for all students	Mean GPA for ONR students	Mean GRE (all students	Mean GRE (ONR students)
1 1992	19	N/A	2.74	N/A	N/A	N/A
2 1993	19.3	N/A	2.92	3.2		
3 1994	19.8	N/A	2.95	3.2		
4 1995						

A Appendix

A.1 Newspaper Articles

Academia, National Laboratory and Industry: A Unique Partnership

Mohan J. Malkani, Decatur B. Rogers, Satiderpaul S. Devgan,
Mohammad Bodruzzaman, Saleh Zein-Sabatto, Ann Blackshear/
Joel Davis/Charles Glover/Hubert Rucker/Robert Pap

Center for Neural Engineering, Tennessee State University/
Office of Naval Research/Oak Ridge National Laboratory/
Meharry Medical College/Accurate Automation Corporation

Abstract

The Center for Neural Engineering (CNE), funded by the Office of Naval Research, represents a novel and innovative experiment in research consortiums. The CNE is a partnership between Historically Black Colleges and Universities (HBCUs), industry, and a national laboratory which snergistically integrates its partners' diverse strengths into a coherent organization. The CNE consists of researchers from two neighboring HBCUs: Tennessee State University (TSU) and Meharry Medical College (MMC), Accurate Automation Corporation (AAC) a small business, high-technology research and development firm in Chattanooga, TN and the Oak Ridge National Laboratory (ORNL) one of the largest multi-disciplinary national laboratories owned by the U.S. Department of Energy with a long track record of pioneering research and development. The main objectives for the CNE are: (1) to further research in biologically motivated artificial neural network (ANN) engineering, (2) to create a conduit for technology transfer, and (3) to enhance the education and career development of minorities and women. The focal points of this paper are interactions between the Center's partners on joint research projects, educational opporunities, the exchange of personnel, and the Center's growth through leveraging its resources.

Introduction

The Center for Neural Engineering (CNE) funded by the Office of Naval Research (ONR) is an innovative and unique partnership between Historically Black Colleges and Universities (HBCU), industry, and a national laboratory. The main objectives of the CNE are: (1) to further research in biologically motivated artificial neural network (ANN) engineering, (2) to create a conduit for technology transfer, and (3) to enhance the education and career development of minorities and women. The CNE relies on the synergistic integration of its partners' diverse strengths to achieve these objectives. The Center consists of researchers from two neighboring HBCUs: Tennessee State University (TSU) and Meharry Medical College (MMC), Accurate Automation Corporation (AAC) a small business, high-technology research and development firm in Chattanooga, TN and the Oak Ridge National Laboratory (ORNL) one of the largest multi-disciplinary national laboratories owned by the U.S. Department of Energy with a long track record of pioneering research and development. The CNE's success allows it to serve as a role model for institutions.

The idea for the CNE started during a five day tutorial based workshop on neural networks. The workshop was funded by the National Science Foundation at the request of Tennessee State University (TSU). The purpose of the workshop was threefold: (1) to expose 22 engineering faculty from 11 HBCUs to ANN techniques, (2) to help them apply these techniques to their areas of research interest, and (3) to provide a forum for the faculty to initiate joint course development and research. The workshop was taught by renowned scientists and engineers from academia, industry, and federal agencies.

The enthusiasm generated by the congenial interaction among the participants allowed the formation of a team, initiated by industry partner AAC, to respond to a Broad Agency Announcement (BBA) from the ONR. The BBA was for a research effort in biologically motivated neural networks. In response to the team's proposal, a site visit was arranged for the ONR Program Manager to meet with researchers from TSU, MMC, AAC, and ORNL. This led to the establishment of the Center for Neural Engineering at Tennessee State University in May 1992.

In the following sections a description of the CNE activities is given. It starts with a discussion of the interactions between the Center's partners by focusing on the joint research projects, educational interaction, and the exchange of personnel. This is followed by a discussion of the benefits to HBCUs and minority institutions (MIs) as a result of leveraging the Center's resources.

Interaction Among Consortium Partners

The research goal of the CNE is to develop biologically inspired neural network algorithms and apply these algorithms to real-world engineering problems. To achieve this goal requires overcoming the problem of unfamiliarity. Unfamiliarity on the part of most physical scientists and engineers who do not have an adequate overview of the multitude of biological processes. Unfamiliarity on the part of most biological researchers who do not have an adequate set of quantitative skills to analyze the vast array of data that has been collected. In order for engineers to apply biologically inspired techniques to their problems, biological processes must be distilled into a representation that is useful for the engineer. Part of the CNE research objective is to educate engineers on a select number of biological systems and allow the engineers to develop suitable representations. Hopefully this will serve a dual purpose. First, it will provide engineers with a description of biological processes in a familiar language and allow them to assess the utility of these processes in helping solve the problem at hand. Second, it may provide biologists with a quantitative framework to describe their data. We realize that this is a difficult research area but it is one that must be pursued and one where the talent in the CNE can make a contribution.

The common research theme among all consortium members before the formation of the CNE was the study and use of neural systems. TSU, AAC, and ORNL have a history of using artificial neural networks (ANNs) for a variety of applications. TSU researchers have used ANNs in signal processing and control problems. AAC researchers use ANNs for control of robotic manipulators, fault diagnoses, and filtering applications. ORNL researchers have applied ANNs to a variety of sensor-based pattern recognition and machine learning problems. However, these institutions had little or no experience in using biologically motivated neural algorithms. On the other hand, MMC has a distinguished reputation in the study of neurophysiology, particularly in the areas of auditory information processing and sensory-motor control. Thus, the first order of business for the CNE was to educate the physical scientists and engineers in neuroscience.

In the summer of 1992, a researcher from MMC presented a weekly series of highly interactive and educational seminars on neuroscience to the other consortium members. This created a congenial relationship among all members of the CNE. In fact, this led the two HBCUs, TSU and MMC, to initiate collaborative research projects for the faculty, graduate and undergraduate students.

To date, the TSU and MMC collaboration has led to the design of a neural network and adaptive wavelet-based auditory system to mimic neural firing patterns in the auditory cortex of a rat's brain. The data from the auditory cortex in rats was collected at MMC and analyzed at the CNE signal processing lab. The data on evoked potential collected from rat's auditory cortex is valuable for evaluating the effects of chronic alcohol consumption at the mid-level of the auditory pathway. This data was collected by a Ph.D. student in physiology from MMC with weekly help of electrical engineering undergraduate students from TSU. In addition, the Ph.D. student aided the CNE faculty and undergraduate students in developing neural models of the data[1,2].

Recently, TSU and MMC researchers have begun a new collaborative effort in the area of sensory-motor control. A researcher at TSU has developed a spherical joint controller and is in the process of developing a biologically motivated neural network controller based on research carried out at MMC on sensory- motor control. MMC has shown added interest in this project due to its potential application for paraplegics[3]. Exploring this apllication would create an even greater synergy be-

will bring ten nationally renowned scientists to the Center by the end of the 94 Spring academic year. The lecture series has provided the Center with tremendous exposure. The exposure has worked two ways; it educates the CNE members to new research and it educates the lectures on the CNE's research.

The Board has been instrumental in opening new avenues that might not have been available otherwise.

References

1. W. Garrison. "Neural network-based modeling of auditory response to pure tones using time domain features." Senior Project, submitted to the College of Engineering and Technology, Tennessee State University. April. 1993.
2. M. Yancy, "Neural network-based modeling of auditory response to pure tones using frequency domain features." Senior Project. submitted to the College of Engineering and Technology, Tennessee State University, April. 1994.
3. M. Bodruzzaman. M. Zein-Sabatto. M. Malkani, H. Szu and R. Sacks. "Neuromuscular signal decomposition for diagnosis and prosthetis control using Hopfield Neurochip," - submitted to World Congress on Neural Networks, Sandiego, CA, June 4-9, 1994.
4. T. Robinson, M. Bodruzzaman. M. Malkani. R. Pap and K. Priddy, "Search for an improved time-frequency technique for neural network-based helicopter gearbox fault detection and classification." - submitted to World Congress on Neural Networks. Sandiego, CA. June 4-9, 1994.

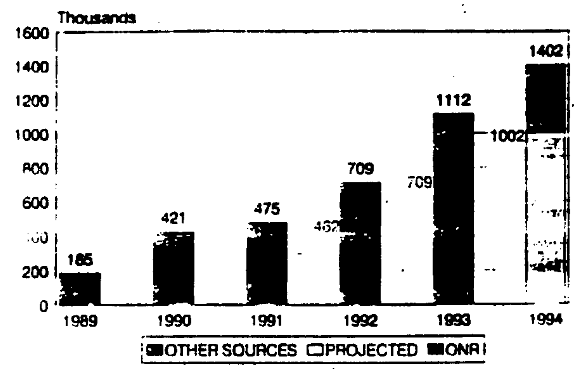


Figure 1. Funded Research Dollars

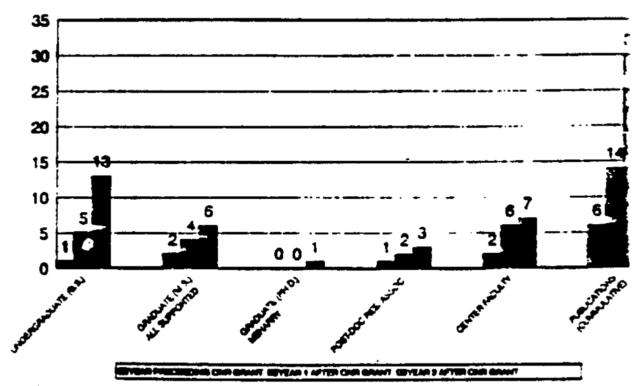
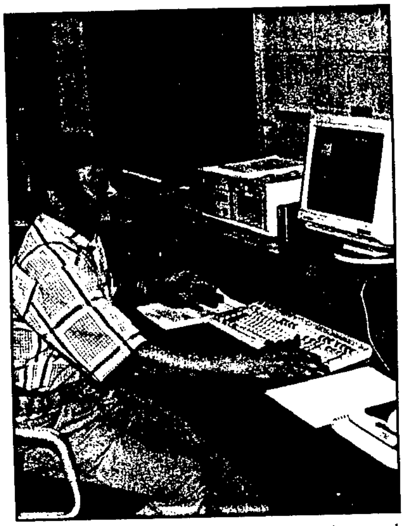


Figure 2. Research Activity in Neural Netwo

Neural Networks Blend Engineering, Biology

TSU's Center for Neural Engineering is mimicking human brain activity in engineering systems.



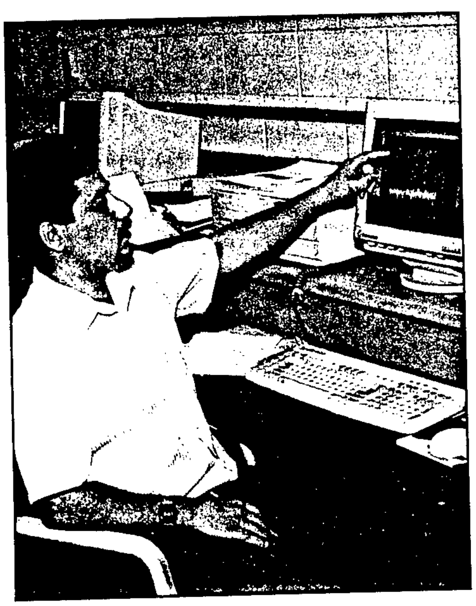
Wen-Ruey Hwang, former research associate and new faculty member in engineering, observes the behavior of an airplane model. His work is part of a project conducted for NASA-Lewis Research.

Have you ever been at a party where you're talking with people standing around you, and your ear tunes to a conversation across the room? How do you select that particular voice, especially in a crowd?

It is that kind of curiosity that attracts organizations like NASA, the U.S. Navy, high-tech corporations, and numerous progressive research institutes and universities to Tennessee State University's Center for Neural Engineering (CNE).

TSU engineers are developing ways to mimic biological processes in artificial neural networks (ANNs) and applying biological processes to intelligent systems, like robots. These innovative engineers call the process "neural engineering;" the lay person would call it an amazing re-creation of how the central nervous system operates.

"That is what neural engineering is all about — biologists and engineers understanding each other's language," said Mohan Malkani, associate dean for the College of Engineering and Technology and director of the Center for Neural Engineering.

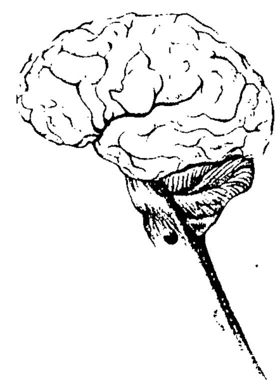


Othman Alsmadi identifies random input through a barometer system that mimics an advanced model of an airplane system.

For example, Mohammad Bodruzzaman, assistant professor of electrical and computer engineering at TSU, is working with colleagues at Meharry Medical College to develop auditory neural networks, which would use the kinds of neural responses that occur when someone hears a voice from across a room.

Bodruzzaman is also working, in collaboration with Accurate Automation Corporation of Chattanooga, to develop and use such auditory systems for diagnosing faults in a helicopter gearbox. The process will allow pilots and crews to detect problems in the helicopter gearbox through accoustical data that would detect any abnormal sounds, so that personnel will not take off if mechanisms are not operating properly. TSU engineers have also formed a partnership with researchers at the Oregon Institute of Science and Technology to study speech recognition patterns.

Other applications of artificial neural networks are conducted in the medical field. For instance, Pacific Northwest Laboratory reports that because of the way they process information, ANNs can diagnose heart



attacks with better accuracy than physicians and read pap smears better than clinicians. The Center for Neural Engineering is in the initial stages of collaborating with Pacific Northwest and Cal Tech on a medical diagnosis project.

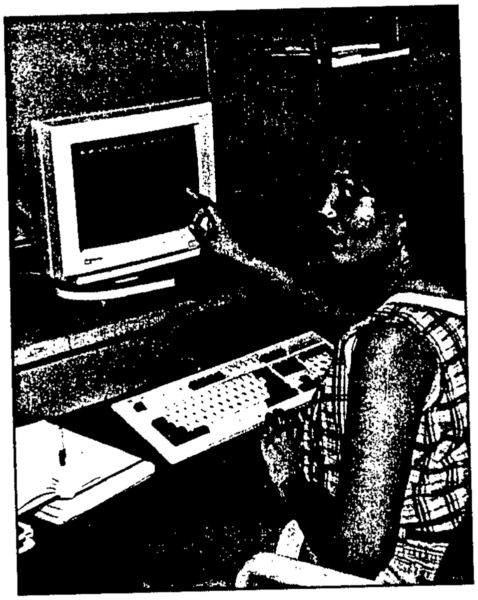
Neural networks open up many possible applications for business and industry. Tennessee State University joins an elite group of seven colleges nationwide — Cal Tech, Michigan, Stanford, University of Southern California, SUNY-Buffalo and California-Berkeley — who were selected by NASA to participate in a Small Business Technology Transfer Program. Saleh Zein-Sabatto, assistant professor of electrical and computer engineering, spent his summer developing a three-dimensional robotic wrist.

"This gives the robot more flexibility and more intelligence, with movements similar to the human joint," said Zein-Sabatto.

Zein-Sabatto said he will complete the development of the wrist concept this year, then business and industry can begin to manufacture the wrists. As a researcher in the CNE, which was established through a $1.3 million grant from the Office of Naval Research, Zein-Sabatto recently completed a two-dimensional spherical joint for the U.S. Navy. He also tests his joint on a mechanism which can perform visual functions, like tracking objects.

The Navy grant "provided a stimulus to bring together a consortium of four institutions to get people thinking about neural engineering," said Joel Davis, manager of the Office of Naval Research. The CNE involves the work of not only Tennessee State University, but also Meharry Medical College, Oak Ridge Laboratories and Accurate Automation Corporation.

Davis says that for TSU, the Center for Neural Engineering means "national prominence" and "net-



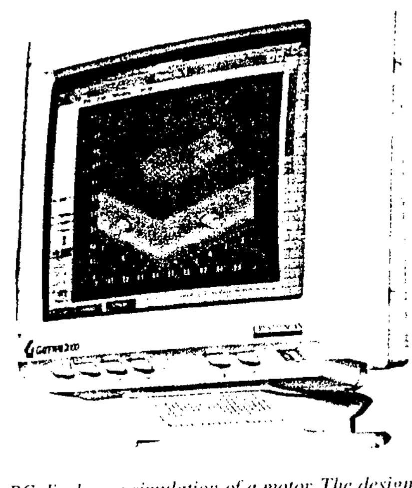
Tretessa Johnson has modeled neurons on her computer, demonstrating ways in which computer science has joined biology and engineering in the interdisciplinary field of neural engineering.

working opportunities that were not there before." For TSU students, the CNE brings greater recognition and better educational opportunities as TSU is "on the cutting edge of one of the new technologies of the 1990s," said Davis.

For another project, NASA-Lewis Research Center is providing TSU $200,000 per year for the next three years to develop an intelligent neural controller for airplanes. The intelligent neural controllers will be operated through personal computers.

Malkani said computer scientists will be the next group of experts to join the interdisciplinary neural engineering team. Engineering students are already using PCs to develop intelligent systems like the airplane robotic controllers.

And Tennessee State University is prepared to be among the innovators in incorporating other disciplines applying new techniques in the neural engineering field—sophisticated techniques that are also as ordinary as what happens at your typical cocktail party.



This PC displays a simulation of a motor. The design is similar to that of an active vision tracker, which tracks the movement of objects, developed by Saleh Zein-Sabatto of TSU's Department of Electrical Engineering.

College of Engineering and Technology

The College of Engineering and Technology offers ABET accredited Bachelor of Science degree programs in Architectural, Civil, Electrical and Mechanical Engineering. The College also offers Bachelor's degree programs in Aeronautics and Industrial Technology with concentrations in Airway Electronics Systems and Computer Integrated Manufacturing. The graduate programs in engineering provide training leading to the Master of Engineering degree with concentrations in Civil, Electrical and Mechanical Engineering. The curricula in these programs are structured to graduate quality students capable of earning Ph.D. degrees in Engineering.

The College is housed in the Andrew P. Torrence Engineering Building with an overall floor space of 60,000 square feet. It has designated 16,750 square feet of floor space for research and development with 23 laboratories that support academic programs and research. These facilities include research laboratories and equipment that are available to faculty and students participating in research. A CamScan Scanning Electron Microscope (250,000X), Gigaku Geigerflex X-Ray Diffraction Machine, AT&T 3B2-310 Microcomputers, SUN SPARC stations, Wiltron Programmable Network Analyzer, Ka-Band Sweeper, AUTOCAD and computer integrated manufacturing work cell are some of the specialized equipment available in the College.

Dr. Decatur B. Rogers, Dean of the College of Engineering and Technology, (center) pictured with some of his students.

Research and Training Funding
Fiscal Years 1990-1994

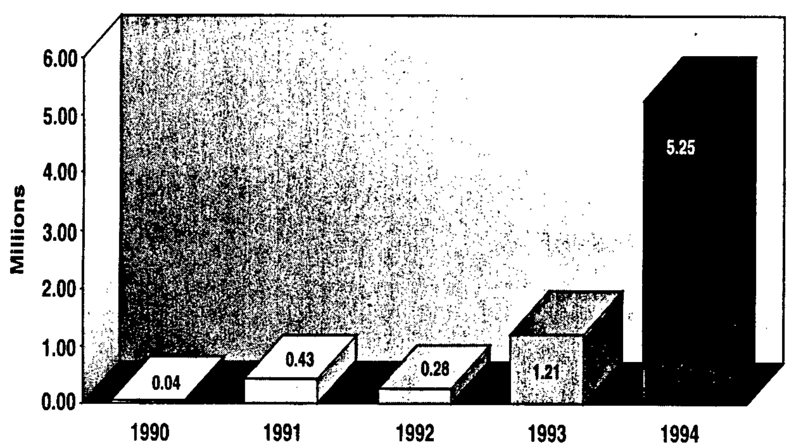


FIGURE 5

The College of Engineering and Technology has several precollege programs designed to attract minorities into science and engineering fields. These programs have provided TSU the opportunity to work with a number of outstanding minority students.

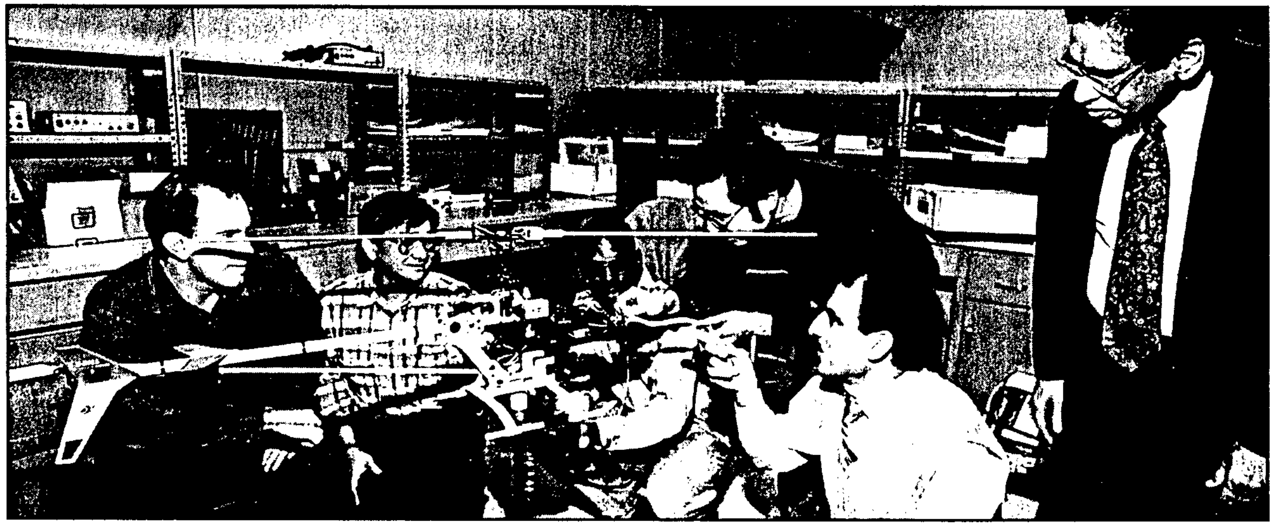
The College of Engineering and Technology has 28 FTE faculty members with a student population of 882. Over the last five years, the College has graduated 540 students at the baccalaureate level with 20

(continued)

College of Engineering and Technology

(continued)

percent of this group entering graduate studies at major institutions. During this five-year period the College received more than $7 million in research grants and contracts that resulted in 18 published papers and 25 technical presentations. The College has major grants and contracts from the ARPA, Army, Navy, Air Force, NASA, and DOE. It conducts research in computer modeling and simulation, AI/Expert Systems, Fuzzy Logic, Transportation Planning and Modeling, Biomedical Applications of Signal Processing, Hazardous Waste Management, Robotics and Machine Vision, Stress Analysis, Software Engineering, Electronic Microcircuit Packaging and Material Processing, Heat Transfer, and Hydraulics. The highlight of research at Tennessee State University for fiscal year 1994 was the phenomenal success of the College of Engineering and Technology in acquiring extramural funds. The College enjoyed an incredible 334 percent increase over fiscal year 1993 as illustrated in Figure 10. For fiscal year 1994, the College was awarded more than $5 million.



The Electrical Engineering Department is developing an intelligent high control system for an advanced model airplane. It is being tested on a immature helicopter in the Electrical Engineering lab. Shown at work on the model from left to right are: John Kuschewski, post-doctoral student; Wen Ruey Hwang, post-doctoral student; O. Omitowoju, graduate student; Yixiong Zheng; Dr. Saleh Zien-Sabatto, Associate Professor, Electrical Engineering; Dr. Mohan Malkani, Associate Dean, Engineering and Technology.

Decatur Rogers

- Predictive Maintenance Techniques, Martin Marietta Energy Systems, $20,000
- ITC-Pre-Engineering Program, Tennessee Department of Health, $137,000
- Project Prime, Mayor's Employment Training Agency, $62,883
- Enhancement & Mobil Recruitment, National Science Foundation, $233,020
- Pre-Freshman Enrichment Program, U.S. Department of Energy, $16,902
- G.E., ECI, General Electric, $50,000
- Chair of Excellence, Department of Energy, $400,000
- AT&T E.E./M.E., AT&T, $25,000
- Alcoa, Alcoa Foundation, $5,000
- 3M, 3M Corporation, $2,500
- Environmental Education Consortium, Oak Ridge Associated Universities, $41,179

Decatur Rogers and Mohan Malkani

- Minority Participation in Science, Engineering & Math, Office of Naval Research, $800,000

(continued)

College of Engineering and Technology
(continued)

ARCHITECTURAL ENGINEERING
Walter Vincent
Summer Light Efficiency Program, State of Tennessee, $48,000

CIVIL ENGINEERING
Farouk Mishu
• Martin Fork Stability Analysis with Slit Load, U.S. Engineering District, $25,000

ELECTRICAL ENGINEERING
Mohan Malkani
• Minority Institution Traineeship Program, EPA, $100,000.
• Intelligent Aircraft Controller, McDonnell Douglas Aerospace, $60,820
• Nuclear Energy Training, Oak Ridge Institute, $6,000.
• Opportunities in Neural Engineering, Office of Naval Research, $212,257
• Center of Neural Engineering, Department of Navy, $440,804

Rucele Consigny
• Research Initiation, Supplementary and Enhancement Program ,Tennessee State University, $6,850

Mebenin Awipi
• Lab for Radiation Studies, Prairie View A&M Research Foundation, $40,000

Satinderpaul Devgan
• Engineering Service to Raytheon, Raytheon Equipment Division, $88,000
• Undergraduate Student Research, NASA, $24,000
• Wind Power Distribution System, Midwest Research Institute, $298,411
• Manufacturing Process for Electronic Packaging, Defense Electronic Supply Center, $126,690
• CEC at North Carolina A&T State University, North Carolina A&T State University, $75,000

Saleh Zein-Sabatto
• Integrated Robust Neuro Controller, NASA, $191,836

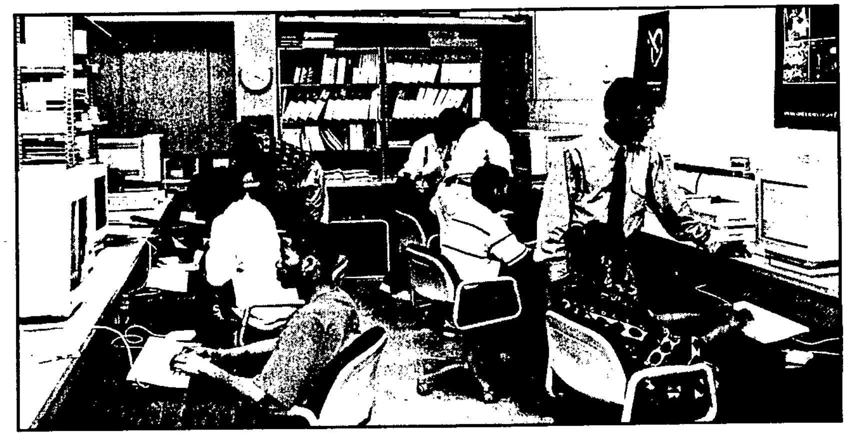
Mohammmad Bodruzzaman
• Neural Network Monitoring and Control of Fluidized Bed, DOE, Office of Fossil Energy, $99,948
• On Line Health, Department of Air Force, $541,368

AERONAUTICAL AND INDUSTRIAL TECHNOLOGY
William McClain
• Teledyne Research, Teledyne Lewisbury-TRAP, $34,343

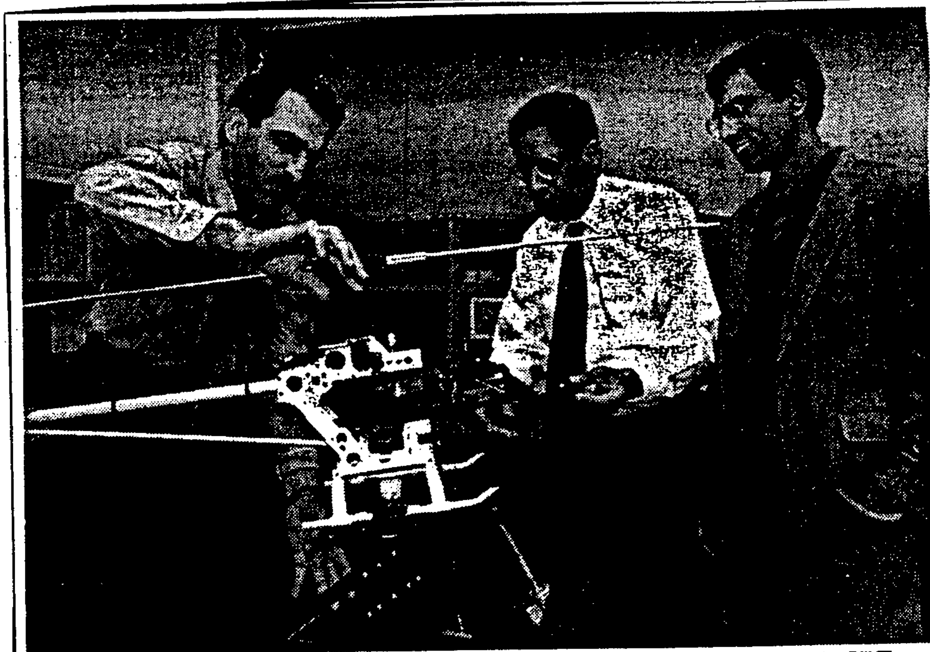
MECHANICAL ENGINEERING
Dilip Chaudhuri
• Characterization of Diamond-like Carbon Films, NASA, $453,303

Chinyere Onwubiko
• Probabilistic Design & Axiomeric Design Assembly, NASA, $400,702

Yvonne Clark
• Heat Pump Test Facility to Evaluate Different Refrigerants, Martin Marietta Energy System, $181,688



Dr. Mohammad Bodrruzzamon is shown with his students in the Center for Neural Engineering Laboratory.



NBJ photo by Bill Thorup

Scientific intersection

Robotics and biology collide in work being done by scientists Saleh Zein-Sabatto, Mohan Malkani and Mohammad Bodruzzaman at Tennessee State University's Center for Neural Engineering. See story, page 6.

Robotics, biology take on new twist at TSU's neural engineering center

By Cyrus Afzali

Creating robots and other devices that can mimic the abilities of the human brain may sound like something from the Sci-Fi Channel to most people, but for students and faculty in Tennessee State University's Center for Neural Engineering those concepts are reality.

The center, started about three years ago and funded by the federal Office of Naval Research, uses a blend of engineering and biology in its projects.

One of the agencies it works with is NASA.

The space agency recently awarded the center a $100,000 grant to develop a fully functioning robotic wrist capable of the same movements as a human wrist.

NASA's Lewis Research Center in Ohio is giving the university $150,000 annually for three years to develop an intelligent neural controller for advanced airplanes.

"This is what neural engineering is all about," says Mohan Malkani, associate dean of the College of Engineering and Technology and the center's director.

"It's about developing ways to mimic biological processes in artificial neural networks and applying this research to intelligent systems like robots.

"It's an amazing recreation of how the central nervous system works, and it's on the cutting edge of technology for the '90s," he says.

Malkani says one of the advantages of TSU's program is that undergraduate students have hands-on involvement in the projects.

"Many programs only have graduate students doing neural engineering. We also sent a student to Cal Tech last summer to do research in neural networks," he says.

Mohammad Bodruzzaman, associate professor of electrical and computer engineering, is using neural networks in aircraft to monitor sounds and alert pilots of trouble based on changes in those sounds.

"The main objective is to develop neural architecture based on biological principles and apply it to engineering problem solving," he says.

Saleh Zein-Sabatto, an assistant professor of electrical engineering, says the system could save valuable time in situations like a military aircraft emergency.

"It's a sophisticated system. If something fails, it will recognize that and recommend the best control actions.

"If an airplane is shot at and part of the wing is gone and the thrust is gone, it may suggest actions for a safe landing or eject a pilot over a friendly zone rather than an enemy one.

"It could save a couple of seconds or minutes, which is significant," Sabatto says.

"We work closely with Meharry Medical College's neuroscientists. We learn how the biological neural network works in the human and about different areas in sensory and brain processing," Bodruzzaman says.

Using that information, the goal is to develop an artificial system that mimics biological neural network activities.

The system Bodruzzaman has developed is currently in the laboratory test phase. By distinguishing between different sounds, the system can diagnose faults in a helicopter gear box.

The technology will allow pilots to detect problems so aircraft with equipment problems will not be flown.

"Once we build an artificial auditory system, we can use it to develop an auditory system for robotics and it can do whatever a human brain does," he says.

In the medical area, the networks show promise in diagnosing problems such as neural muscular and cardiac diseases.

"Artificial neural networks are good at pattern recognition. When you have cardiac signals, by looking at them, it can tell you if they are abnormal and can predict the risk of cardiac failure.

"The goal is to predict whether there will be any change in the future and especially to predict sudden cardiac deaths."

Undergraduate students are trained on designing the networks. Graduate students also perform research and publish papers.

Bodruzzaman conducted a project last year for the U.S. Air Force and developed a system to monitor stress on aircraft bodies and predict structure fractures before they occur.

Although the funding of the work comes from the military, he says there are many different concepts that fit with the technology.

Sabatto is the principal developer of the fully functioning robotic wrist.

He expects to complete development of the wrist this year.

"Right now, robots rotate in one degree of direction. We're trying to create a joint similar to a human shoulder or wrist with three degrees of freedom that will be controlled by neural networks."

Another possible application for the arm is performing medical procedures.

Sabatto says another positive aspect of the program is it involves academia and industry.

"What we learn will be transferred to industry who will carry out the production."

Malkani says computer scientists will be the next group of experts to join the interdisciplinary neural engineering team. ■

NASA joins hands with TSU in Neural Engineering

University is awarded half million in grants

It's a new technology, barely a decade old, and it's being applauded far and near for its ability to mimic the processes of the human brain. It's called neural engineering, a blend of engineering and biology, and it's causing high-tech giants like NASA to join forces with Tennessee State University in research and development of neural engineering systems.

NASA recently awarded a $100,000 grant jointly to the University's Center for Neural Engineering and its industry partner to further development of a three-dimensional robotic wrist. Mid-South Engineering, a local company, is the University's partner in this project.

In another project, NASA-Lewis Research Center is providing the University $150,000 per year for three years to develop an intelligent neural controller for advanced model airplanes. The intelligent neural controllers will be operated through personal computers.

"This is what neural engineering is all about," said Mohan Malkani, associate dean for the College of Engineering and Technology and director of the Center for Neural Engineering.

"It's about developing ways to mimic biological processes in artificial neural networks and applying this research to 'intelligence' systems, like robots. We call it an amazing recreation of how the central nervous system works, and it's on the cutting edge of technology for the 90s."

The robotic wrist, that has so intrigued NASA, gives the robot more flexibility and more 'intelligence' with movements similar to the human joint, said Saleh Zein-Sabatto, its principal developer. Zein-Sabatto, assistant professor of electrical and computer engineering, expects to complete development of the concept this year, then business and industry will begin to manufacture the wrist. Zein-Sabatto also has recently completed a two-dimensional spherical joint for the U.S. Navy.

Another application of this technology is auditory neural networks which can distinguish between different sounds much like the human brain can distinguish slight differences. Mohammad Bodruzzarnan, assistant professor of electrical and computer engineering, is using these auditory systems to diagnose faults in a helicopter gear box. This technology will allow pilots and crews to detect problems so that personnel will not fly if systems are not operating properly. When the auditory neural networks detect abnormal sounds, it supplies acoustical data to warn crews of the potential problems. Bodruzzaman is working in collaboration with Accurate Automation Corporation of Chattanooga in developing this system.

The medical field also makes use of artificial neural networks (ANNs). For instance, Pacific Northwest Laboratory reports that because of the way they process information, ANNs can diagnose heart attacks with better accuracy than physicians and read pap smears better than clinicians.

The Center for Neural Engineering is in the initial stages of collaborating with Pacific Northwest and Cal Tech on a medical diagnosis project.

"One of the major advantages," Malkani said, "of doing this type of research and development in our College of Engineering and Technology, is that we can offer students a first-hand learning experience with some of the latest technological advancements in the field. Undergraduate students as well as graduate students are prepared to enter the work force with the latest skills and knowledge available to them in this area."

Malkani said computer scientists will be the next group of experts to join the interdisciplinary neural engineering team. Engineering students are already using PCs to develop intelligence systems like the airplane and robotic controllers.

Education

TSU neural engineering research receives half million dollars in grants

by Annette Ansari

Neural Engineering is a new technology which blends engineering and biology. Mohan Malkani, Associate Dean for the College of Engineering and Technology and Director of the Center for Neural Engineering, explains that neural engineering is "about developing ways to mimic biological processes in artificial neural networks and applying this research to intelligent systems, like robots."

Tennessee State University's Center for Neural Engineering, supported by the Office of Naval Research, and its industry partner Mid-south Engineering has been awarded a $100,000 grant from NASA to develop expertise in the area of neural engineering, to look into the concepts of neuro-network in learning, specifically to learn how the rain works in thinking and decision making. This technology will further the development of a three-dimensional robotic wrist.

"Proposals were submitted to NASA from organizations nationwide," said Saleh Zein Sabatto, Assistant Professor in the Department of Electrical and Computer Engineering. "There were 72 proposals submitted and Tennessee State is one of seven recipients of the award," he added.

The project called the "Spherical Motor and Neural Controller for Micro-Precision Robot Wrist" is expected to be completed by September of this year, at which time the department will resubmit to NASA. The department could be the recipient of $500,000 over the next three years to further the manufacturing of the robotic wrist.

Tretessa Johnson, a student in the College of Engineering, uses the computer to develop neural intelligence.

"The robotic wrist is important because up till now robots have had only one-dimensional movements," said Sabatto "The new design will have a 3-dimensional capability and will be especially useful in robots for space applications and for medical surgery," he said.

"The new robotic wrist would be able to do more precision surgery with a greater flexibility similar to the human joint," Sabatto said. Sabatto is the principal developer of the 3-dimensional wrist.

Another grant by NASA, Lewis Research Center is providing the University with $150,000 per year for three years to develop an intelligent neural controller for advanced model airplanes to be operated through personal computers.

Mohammad Bodruzzaman, assistant professor of electrical and computer engineering, is using the technology of auditory neural networks which can distinguish between different sounds much like the human brain to diagnose faults in a helicopter gear box. Its development will allow pilots and crews to detect problems so that personnel will not fly if systems are not operating properly.

Students at the College of Engineering and Technology are experiencing first-hand with some of the latest technological advancements in the field. Malkani said that engineering students are already using PCs to develop intelligent systems like the airplane and robotic controllers and they will be the next group of experts to join the interdisciplinary neural engineering team. ♦

Saleh Zein Sabatto, assistant professor in the Department of Electrical and Computer Engineering at Tennessee State University, demonstrates the 3-dimensional robotic wrist.

• Wednesday, March 15/ 1995 — THE TENNESSEAN

Neural engineers creating computer 'brain'

By LISA BENAVIDES
Staff Writer

Like experienced drivers who can hear what's wrong with their car engines, computers at Tennessee State University are "learning" to detect faults in a helicopter gearbox too subtle for humans to recognize.

Using the relatively young field of neural engineering, TSU researchers are developing a computer that will warn pilots when a helicopter is malfunctioning and recommend an action to take. The project is financed by the armed services, which lost several helicopters in Operation Desert Storm when sand got into gearboxes.

What puts neural engineering on the cutting edge is that computers are doing more than spitting out the facts they're given. In an image straight from science fiction, TSU's machines are able to learn.

"This is an amazing recreation of how the central nervous system works," Mohan Malkani, director of TSU's Center for Neural Engineering, said. "The technology is so new it's still in the development stage and we're trying to bring it to the application stage."

Among the practical applications TSU is working on: creating a robotic wrist that imitates human movement for NASA, and controlling prosthetic limbs by brain waves.

Almost all of the knowledge humans have is found in networks of tiny nerve cells inside our brains. In neural engineering, researchers use computer software to mimic the interconnections of some of those nerve cells.

Because there are about 100 trillion interconnections, researchers have been able to recreate specific functions such as motor skills or voice recognition, but they can't recreate an entire brain.

Neural networks differ from other computer programs in that they "learn" through a training process, as a human learns by trial and error. And they are able to make a connection between something they've learned and something they've never seen.

For example, if you entered into a computer the pictures and names of thousands of cars, then showed the computer just the

▶ Turn to PAGE 2A, Column 2

Nina Long • Staff

TSU assistant professor Saleh Zein-Sabatto, left, helps Oluwole Omitowoju equip a model helicopter with a computer.

FROM PAGE 1A

bumper of a car, it could cull through its memory to identify the car.

Where the neural network outperforms humans is, it never forgets and can identify something from the smallest fragment.

A distinctive aspect of this form of artificial intelligence is that it combines engineering and biology. TSU researchers are working with Meharry Medical College to understand how humans learn and think, so they can recreate those processes with machines.

"When we started, we didn't know ABC about biology," admitted Malkani, who started the neural engineering department seven years ago.

Now the engineers are fluent in neurons and synapses, the language that describes how the brain works.

"This is definitely the wave of the future, because it can tackle a class of problem that up until now hasn't been reached."

MONGI ABIDI
UT engineering professor

Mongi Abidi, a University of Tennessee associate professor who has worked with TSU on some neural engineering projects, said "You have things that fool a human and the networks are able to find the patterns from a large amount of data.

"That's why it's called artificial intelligence, because it's returning more information than what you give it."

Although artificial intelligence has been around for about 30 years, the field of neural engineering has just taken off in the past eight years. Vanderbilt and Middle Tennessee State universities are also doing research in this field.

"People have just started to find practical application for this kind of artificial intelligence," Abidi said.